NOVEL SOURCES OF NUTRIENTS IN URBAN WATERSHEDS

A Thesis

by

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ABSTRACT

Nitrogen, phosphorous and carbon are naturally occurring nutrients that are essential for all organic life. However, the water quality of many water bodies is negatively affected by high concentrations of these nutrients. A large volume of primary research has been published on different nutrient sources and interactions. While it is the general consensus that urbanization affects surface water quality, it is very difficult to determine all possible sources for N and P in these complex watersheds. This thesis summarizes several potential sources for urban watersheds, and groups them into three focus groups. First is a review of current literature and any gaps present. Then an in-depth study of Carters Creek basin where monthly samples were taken by trained professionals and volunteers over the course of two-years. And the final study explores the subject of death and decomposition by examining nutrient transport from buried pets.

Results from the Carters Creek study showed that there were significantly different concentrations of E.coli and nutrients in storm events when compared to normal or low flow events. Additionally higher concentrations were found downstream of known point sources and Carters Creek continues to be impaired for high E.coli values. Our results from the decomposition study found some transport of nutrients downslope from the sources. More research in both studies would assist in further narrowing the interactions between sources of nutrients and watershed systems.

DEDICATION

For my Mom and Dad

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1 INTRODUCTION AND LITERATURE REVIEW

1.1 Urbanization and surface water quality

Eighty-one percent of Americans live in urban centers (United States Census Bureau 2012). The move away from an agricultural or rural way of life to one of living in urban centers commenced in the early 1900's and is continuing today. Between 1980 and 2000 the U.S. experienced a 24% increase in urban population, which is an increase of more than 50 million people. During this time period, urban land use in the U.S. increased by over 34% (Alig et al. 2004).

Urbanization has a well-documented, negative effect on surface water (Cheng et al. 2014; Meyer et al. 2013; Walsh et al. 2005). In 1995, urban runoff was listed as the third most common source of surface water impairment of U.S. rivers (Cheng et al. 2014). The observed changes in surface water quality and quantity in watersheds with a significant portion of urban land use has been termed the *"urban stream syndrome"* (Meyer et al. 2005). The urban stream syndrome was defined as *"the consistently observed ecological degradation of streams draining urban land"* (Walsh et al. 2005). Symptoms of the urban stream syndrome include flashy hydrographs, altered channel morphology, and reduced biotic richness and diversity with an increased dominance of invasive species.

Land use is only one factor that may affect surface water quality. For example, surface water chemistry is also directly related other factors including the geology underlying the watershed, local climate and season, topography and vegetative species

and their associated microbiology which when combined cause the natural diversity observed among surface water chemistries (Aitkenhead-Peterson et al. 2011; Walsh et al. 2005).

1.2 Nitrogen, phosphorus and carbon in urban watersheds

Based on a review of the literature regarding urban surface waters, Walsh et al. (2005) concluded that many different factors, both natural and anthropogenic, can cause observable changes in surface water chemistry, specifically nitrogen, phosphorus and carbon. It may therefore be a challenge to determine the specific source of any changes in urban surface water quality. For example, Walsh et al. (2005) suggested that when nutrient uptake decreased, resulting in higher observable nutrient concentrations in urbanized streams, it may be due to decreased transient zone storage occurring through reduced channel complexity. Furthermore, Walsh et al. (2005) suggested that organic matter inputs to, and their retention in urban streams coupled with stream biological composition (i.e. algae, micro/macro invertebrate diversity) may affect how quickly nutrients are utilized in the stream system. A surplus of nutrients can easily overload an urban aquatic system and will eventually create a negative feedback loop as the organisms that typically use nutrients are outcompeted by algae blooms caused by the increased nitrogen and phosphate concentrations (Walsh et al. 2005). There are several studies that document that NO_3-N and PO_4-P concentrations as low as 0.05 mg L^{-1} can result in an observable increases in phytoplankton biomass and toxic dinoflagellate concentrations in freshwater and estuarial ecosystems (Burkholder et al. 1992; Mallin

and Wheeler 2000; Qin et al. 2013) and this really underscores the importance of Redfield ratio's (Redfield 1934) in aquatic systems. The Redfield ratio of 106:16:1 for C:N:P originally deduced for the oceans, has been used successfully in surface waters (Hecky et al. 1993; Jankowski et al. 2012) and even soils (Cleveland and Liptzin 2007). Jankowski et al. (2012) examined N:P stoichiometry in 27 lakes across a human density gradient in western Washington, USA. They found that by utilizing $d^{15}N$ in their methodology, at a N:P mass ratio of < 15.3 that N-fixation became an increasingly important component of the N cycle accounting for > 50% of freshwater lake budgets in urban watersheds.

The likelihood that there are several sources of N and P which are available for non-point source transport in an urban watershed suggests a more complex relationship among nutrients than originally speculated by Walsh et al. (2005) and requires further research into novel sources. Both nitrogen and phosphorus are nutrients of concern because of their known roles in amplifying harmful algal blooms as instream N and P concentrations increase (Roy and Bickerton 2014).

Nitrogen is present in several forms in surface waters including nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), and dissolved organic nitrogen (DON). Three important factors for the cycling of nitrogen from riparian systems are the source volume, hydrological conductivity, and the mode of transportation (Craig et al. 2008). Sources include enhanced nitrogen deposition supplied through rainfall, sewage effluent, landfill leachate, enhanced mass and hot spots of fecal material such as from concentrated animal feeding operations (CAFOs), fertilizer use, and decomposition

products from the death and decay of animals (i.e. CAFOs, wildlife diseases and road kill) (Driscoll et al. 2003). The amount of nitrogen that is introduced into an ecosystem from these sources is perceived as limited so nitrogen is often added in the form of fertilizer (Cheng et al. 2014). Kaushal et al. (2014) argued that while agricultural non-point sources of nitrogen are a concern, they are much more responsive to Best Management Practices (BMPs), and are much easier to predict due to the consistency in their export. Inversely, in urban watersheds, homeowner lot management and the composition and diversity of plant species in gardens and parks which appear to be dictated by socioeconomics (Hope et al. 2008). Furthermore, different irrigation water chemistries cause noted differences in nutrient runoff and leaching of nutrients after rain events compared to irrigation (Pannkuk et al. 2011; Qin et al. 2013).

Phosphorus is an important nutrient for plant growth and has many similar anthropogenic sources to nitrogen (Qin et al. 2013). Wastewater treatment facilities (WWTFs) are a common source of phosphorus to urban surface waters because it is not removed from sewage effluent during the secondary treatment process (Aitkenhead-Peterson et al. 2011; McCrary et al. 2013). Agriculture (runoff and erosion), animal waste (CAFOs), and forestry (erosion) are also major sources of phosphorus in surface waters of non-urban watersheds (Carpenter et al. 1998). Recent research has been conducted on phosphorus additions to surface water from groundwater during base flow conditions. Roy and Bickerton (2014) determined that highly soluble reactive phosphorus (SRP) concentrations caused by reducing conditions in natural groundwater aquifers may explain high phosphate concentrations found in natural streams not

associated with point sources. Reducing conditions cause PO_4^{3-} to desorp from sediments to which they are normally adsorped. While urban sources of N and P are much more difficult to determine, they may actually contribute more to the overall concentration of N and P in watersheds (Kaushall et al. 2014).

Carbon is a building block and foundation for all organic life. All natural carbon is derived from photosynthesis. Sources of carbon quantified as allochthonous dissolved organic carbon (DOC) or that derived from the watershed itself rather than instream sources (autochthonous) is a consequence of the rainout of pollens and dusts, the interaction of precipitation with vegetative canopy (throughfall) and infiltration through watershed soil (Aitkenhead-Peterson et al. 2003). Autochthonous sources of DOC in surface waters, particularly lakes, are derived mainly from algal cell leakage (Kritzberg 2004). It is postulated that autochthonous DOC is more labile compared to allochthonous DOC (Kritzberg 2004) and DOC utilized by aquatic microbes is either mineralized to CO_2 or transformed to microbial biomass. Allochthonous DOC in urban streams has a percent biodegradability of between 2% and 10% (Cioce 2012). Other studies have indicated that biodegradable DOC (BDOC) in non-urban surface water can vary from 4-68% (Seitzinger et al. 2005; Wiegner and Seitzinger 2001; Weigner et al. 2006). Without labile carbon available as a microbial substrate, N and P in surface waters cannot be cycled as efficiently (McCrary et al. 2013).

Sources of DOC to urban surface waters from anthropogenic sources are derived from WWTFs (Westerhoff and Anning 2000), runoff from impervious surfaces (Hope et al. 2004) and released from urban soils irrigated with sodic water (Holgate et al. 2011;

Pannkuk et al. 2011; Steele and Aitkenhead-Peterson 2012). Furthermore, there is evidence to suggest that urban streams have a higher sodium adsorption ratio (SAR) compared to rural streams and that the increased stream water SAR may result in enhanced leaching of DOC from leaves and plant debris within the stream channel (Steele and Aitkenhead-Peterson 2013).

1.3 *E. coli* in urban watersheds

The sources of *E. coli* and nutrients in urban streams have been examined quite thoroughly over the years. Bolster et al. (2005) and McCrary et al. (2013) postulated that enhanced counts of *E. coli* downstream of WWTFs were the result of their recovery after disinfection and was driven by nutrients in surface water. Bolster et al. (2005) examined chlorine disinfected effluent and McCrary et al. (2013) examined ultra violet light (UV) disinfected effluent. *E. coli* loading to a stream may come from a number of fecal sources, including avian and non-avian wildlife, domesticated animals such as pets and livestock or humans. However, the planning, research, and management of a watershed can reduce contributions from human and domesticated animal waste through the implementation of BMPs (Dickerson et al. 2007). A recently identified source of *E. coli* to urban streams is the stream and bank sediment; *E. coli* was significantly related to the particle size of sediment in as study of bayous in Houston, TX (Brinkmeyer et al. 2015). The percent organic matter in bank and stream sediments has also been implicated in the abundance or survival of *E. coli* in stream sediments (Garzio Hadzick 2010). Sometimes a relationship between stream *E. coli* and stream or stream sediment nutrients is apparent

(Duan et al. 2014), which should not necessarily be considered cause and effect, but a similar source. Yet the interstitial DOC in stream sediment derived from WWTFs was able to be utilized by *E. coli* for prolonged survival (Haller 2009). The re-suspension of stream sediments into the water column during rain events is also possible cause of high *E. coli* counts during rain events in urban streams when stream velocities increase (Characklis 2005; Petersen 2009; Wu 2009). Suffice to say all sources of nutrients and *E. coli* to urban streams have yet to be identified.

1.4 Novel sources of C, N, and P to surface waters: Death and decomposition of animals

One source of nutrients to surface waters may be the transport of animal decomposition products (Aitkenhead-Peterson et al. 2012; Wozniak et al. 2015). Animal decomposition is an important aspect of many of the nutrient cycles (Barton et al. 2013), yet has only recently been acknowledged as a potential source to surface waters. Decomposition allows for a relatively fast incorporation of the nutrients tied up in the organism back into the environment (MacDonald et al. 2014). The contribution of carbon, nitrogen and phosphorus derived from the decomposition of mammals such as road kill (dogs, cats, deer and skunks) and buried pets (dogs and cats) in urban watersheds has not been examined.

Taphonomy, the study of decomposition, is a branch of anthropology that focuses specifically on the process and variables of death and decomposition. Currently, the majority of the research available in the field focuses on forensics to aid criminal investigations. There has been a trend in this research in using the natural occurring

compounds in the decomposition process to help identify clandestine graves (Aitkenhead-Peterson et al. 2012), determine postmortem intervals of cadavers (Aitkenhead-Peterson et al. 2015) and train human remains detection dogs (Alexander et al. 2015). Cadavers release carbon, nitrogen and phosphorus compounds to the soil as part of the decomposition process and these compounds may persist in the soil environment for months to years (Towne 2000; Brathen et al. 2002; Aitkenhead-Peterson et al. 2015). The potential for decomposition products C, N and P to affect local water quality through transport off site is under-researched.

There are many reasons why there is a lack of research on the potential effects of animal decomposition on water quality. One reason is the difficulties that arise when it comes to replications due to variability within the same species. Even within the same soil series, same research methods and same species, variation in decomposition rates are still apparent to the point that it affects the ability to duplicate the experimental results even within a single experiment (Tumer et al. 2013). Also there are difficulties with ethics cited in many studies that has led to the use of domestic pigs or swine as analogues for human cadavers for forensic use (Carter et al. 2008; Stokes et al. 2013). Because of the lack of this type of research from an ecological perspective, the impact that animal decomposition has on water quality within a watershed is unknown. Popular press articles, however, indicate that unsafe disposal methods of dead hogs resulting from the porcine epidemic diarrhea (PED) virus result in nutrients from the decomposition of dead hogs making their way to surface waters (EcoWatch 2014). One recent study at a human donor facility in Texas, USA recognized the potential of nutrient

transport from decomposing cadavers to surface waters (Wozniak et al. 2015). The Wozniak et al. (2015) study examined nutrients in surface water down slope from the facility and in retention basins designed to capture and cycle transported nutrients from the facility. They reported that nitrite and chloride concentrations were significantly higher down slope of the facility compared to concentrations in the retention basins and that P was significantly higher in the retention basin compared to down slope of the facility. Unfortunately, surface water nutrients in the stream upstream of the facility were not quantified because the stream was dry during sampling and so no conjecture on the effect of the facility on surface water quality was made (Wozniak et al. 2015). Aitkenhead-Peterson et al. (2012) noted at the same facility that extractable soil DOC, DON, PO_4-P and K^+ were significantly higher down slope of the facility and called for more research into the transport and potential contribution of animal decomposition products to surface water nutrients.

1.5 Conclusions and objectives for study

Urban and urbanizing watersheds have high concentrations, loads and exports of C, N and P. Research has discovered that municipal sources will produce a constant source of high nutrient loads, even in times of drought through constant flow (Aitkenhead-Peterson et al. 2011). In contrast, land management practices,particularly those involving fertilization will have peaks surrounding application periods (King et al. 2007). Further research is required to create a BMP manual for watershed coordinators,

in order to determine what practice would be the most efficient for their focus area (Williams et al. 2013).

The major objective of this study was to examine potential sources of nutrients and *E. coli* in an urban watershed in south-central Texas, USA.

2 NUTRIENTS IN CARTERS CREEK WATERSHED

2.1 Introduction

Carters Creek has been listed as impaired for *E. coli* since 1999; Burton Creek, a tributary of Carters Creek, has been listed as impaired for *E. coli* since 2006; and Country Club Branch, a tributary of Burton Creek, has been listed as impaired for *E. coli* since 2006 in the Texas Commission for Environmental Quality (TCEQ) Clean Water Act Section 303(d) List and Schedule for Development of Total Maximum Daily Loads (TMDLs) (TCEQ 2013). The goal of this TMDL was to comply withachieve primary contact recreational use water quality standards throughout the watershed. The possible sources of *E. coli* that may cause the impairments include point source pollution from WWTFs in the watershed and several non-point sources associated with the urban and rural areas. There is currently a TMDL implementation plan (IP) for three segments of Carters Creek (segments 1209C, 1209D, 1209L). Because of the small size of the watershed, there has been very little, or sporadic USGS monitoring data of the watershed and so additional data were required to prepare the TMDL IP. An essential component of the TMDL IP was the inclusion of stakeholders. Several meetings were held among stakeholders who included personnel from the Texas Water Resource Institute (TWRI), Texas A&M University (TAMU), Carters and Burton Creek WWTFs and the Cities of College Station and Bryan. Furthermore, an added component of citizen scientists or volunteers to collect surface water samples in an effort to a) increase awareness of

stakeholders in the watershed and b) improve collection from multiple sites within the same timeframe was included in the TMDL IP.

Previous studies have tried to pin-point sources of *E. coli* and nutrients in Carters Creek watershed and have identified some possible sources (e.g. Harclerode et al. 2013; McCrary et al. 2013; Steele and Aitkenhead-Peterson 2013). Harclerode et al. (2013) examined Carters Creek in a nested study and determined that while WWTF contribution for nutrients was expectedly high, *E. coli* appeared to be derived from the older part of the city and commercial land use explained most of the variance in *E. coli* counts. Overall 56% of the variance in *E. coli* counts were described by urban land use in the winter months and 72% of the variance in *E. coli* counts were described by urban land use in the spring in Carters Creek (Harclerode et al. 2013). While Harclerode et al. (2013) reported no relationship between *E. coli* and nutrients in Carters Creek, a follow up study by McCrary et al. (2013) did show a relationship. McCrary et al. (2013) utilized a backward stepwise regression analysis to predict *E. coli* in Carters Creek sub-watersheds where between 82-92% of the variance in *E. coli* counts during high flow and between 55-57% of the variance in *E. coli* counts during low flow downstream of the two WWTFs in the Carters Creek basin were described by combinations of stream water dissolved organic carbon, (DOC), dissolved organic nitrogen (DON), NH_4-N, NO_3-N or PO_4-P. With the recognition that the WWTF will provide N and P for bacterial use, Steele and Aitkenhead-Peterson (2013) examined the potential source of C to Carters Creek and reported that because of the high SAR of Carters Creek sub watershed

surface waters that DOC was readily leached from instream vegetation such as leaf litter and grass clippings swept into storm drains.

It is much easier to regulate and monitor surface water additions from WWTFs, as they are typically recognized as point sources of nutrients. A point source is determined as a permitted discharge of effluent into surface water. There is a lack of research on the possible contributions that a leaking infrastructure such as raw sewage pipes may have on surface water quality (Divers et al. 2013). For example, there are miles of underground sewage pipes in the United States; these vary in age and condition and present the possibility that older sewage pipes may leak thus affecting surface and ground water quality. Base flow that is contaminated with leaking effluent derived from the groundwater may account for enhanced nutrient concentrations in some systems. However, there can be difficulty in locating leaks and funding their repair (Divers et al. 2013). In addition to the municipal pipe systems, there is still a large population of the U.S. that rely on septic tank systems for treating their sewage; these are also likely to leak or more probably, the surrounding soil becomes saturated with nutrients available for runoff creating a non-point source for nutrients (Driscoll et al. 2003).

The major objective of this study was to determine which sub-watershed had a significant effect on *E .coli* counts and nutrient concentrations and exports. A secondary objective was to examine the potential for citizen scientist collections by comparing data collected by trained scientists and data collected by stakeholders and citizen scientists. In addition to the primary objectives, several analyses were performed to elucidate: i) the effect of point source wastewater on urban stream water DOC, DON, ammonium-N,

nitrate-N, orthophosphate-P and *E. coli* counts in urban streams at seasonal, annual and two-year time scales, ii) the effect of non-point source runoff inputs on urban stream water quality, iii) relationships between *E. Also be consistent with instream and in-streamcoli* counts and stream nutrients at multiple spatial scales.

Specific hypotheses for this study are as follows:

H_{o1}: No significant differences in DOC, nutrient concentrations and *E .coli* counts will be observed downstream of WWTFs when comparing urban streams with and urban streams without WWTF at all temporal scales.

H_1: Higher DOC, nutrient concentrations and *E. coli* counts will be observed downstream of WWTFs when compared to other urban surface water locations without a WWTF.

H_{o2}: No significant difference in DOC, nutrient concentrations and *E. coli* counts will be observed when comparing low flow and high flow

H_2: There will be a direct relationship between storm flow and the concentrations of DOC, nutrients and *E. coli* observed in the stream because rainfall induces non-point source runoff.

H_{o3}: There will be no relationship between *E. coli* counts and stream DOC and nutrient concentrations.

H_3: A significant relationship between *E. coli* and stream DOC and nutrient concentrations will be observed using multiple regression analysis.

2.2 Materials and methods

2.2.1 Site description

Carters Creek is a small watershed (HUC 12) in the Lower Brazos River Basin that includes the urban areas of College Station and Bryan. The watershed covers 176 km^2 in a subtropical humid climate receiving approximately 1000 mm of rain per year. Average temperatures for the watershed are highs in August of 35° C and lows in January of 5° C (National Weather Service Weather Forecast Office 2014). Soils in the watershed include several soil series, but are dominated by Alfisols underlain with marine clays and sandstone (Aitkenhead-Peterson et al. 2011).

Land use in the watershed is dominated by developed land where 48% of the watershed is classified under this category by the 2011 National Land Cover Survey (Figure 1). Planted or cultivated (agricultural) (16%), forested (14%), shrub and scrub (10%) and open water and wetlands (11%) complete the land use for the watershed (Figure 1).

2.2.2 Sample collection - routine water quality sampling

Four specific monitoring stations were included under this section (Table 1); three located along Carters Creek and one at the mouth of Burton Creek at its confluence with Carters Creek (Figure 2). Site 21259 is the most downstream sampling location of the three stations on Carters Creek and was used as the discharge point for Carter Creek. Below Site 21259, there is a small section of rural land that is only minimally estimated will contribute to water quality in the area, before Carters Creek empties into the

Navasota River. These samples were collected by TWRI staff each month on the same day that reconnaissance samples were collected by citizen scientist volunteers.

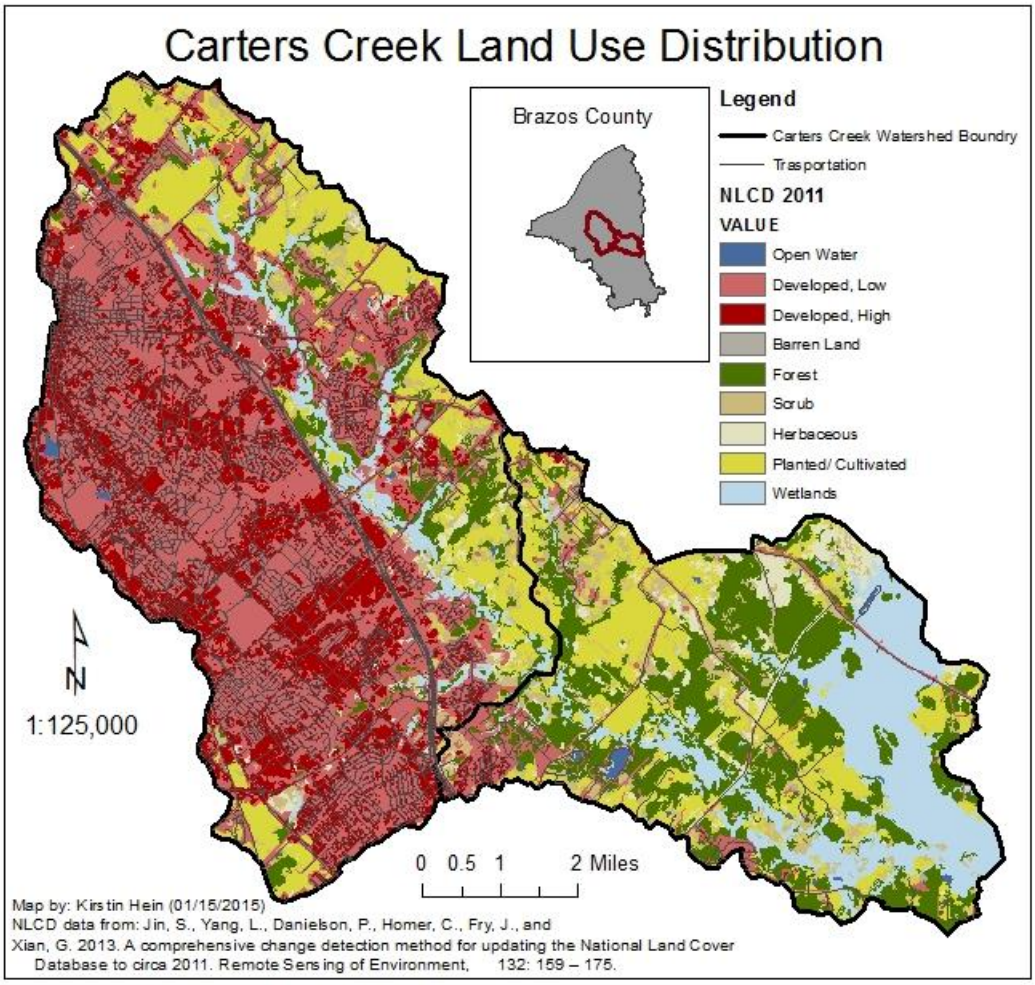

Figure 1. Land cover distribution for the Carters and Burton Creek watersheds. Data from 2011 National Land Cover Database, map created by Kirstin Hein.

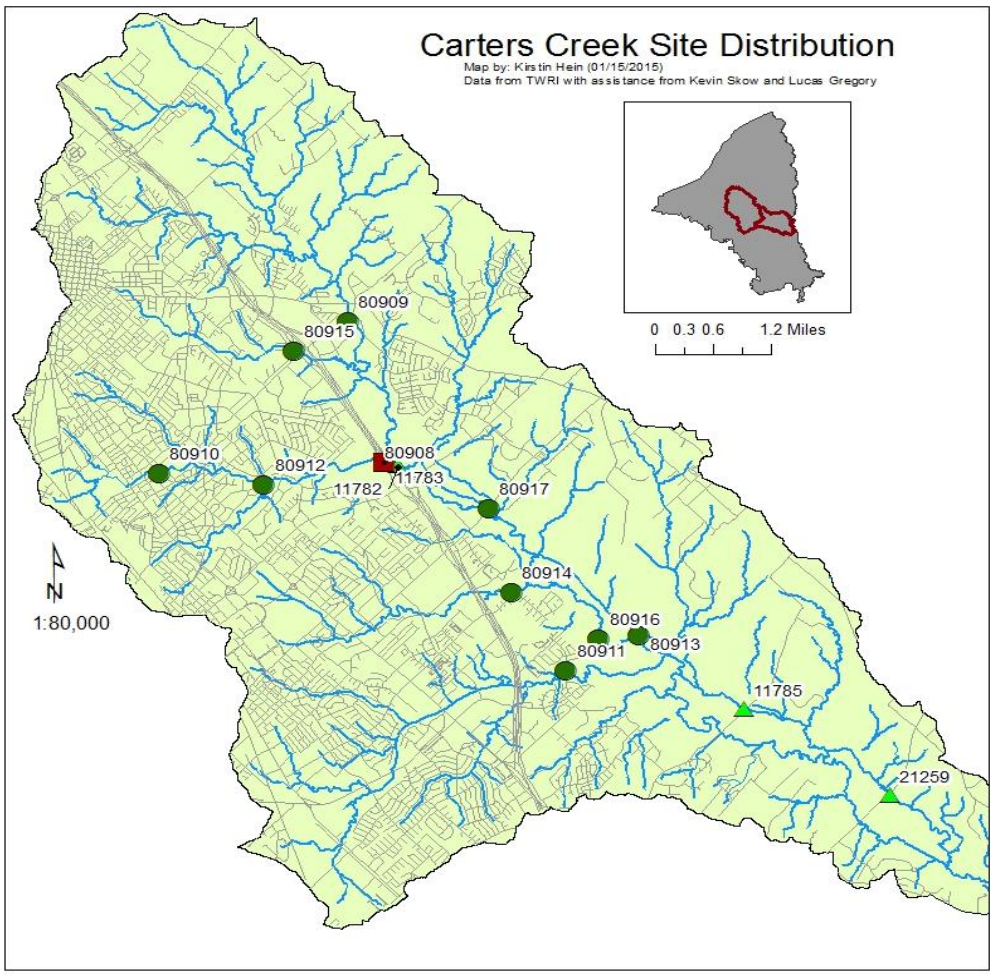

Figure 2. Site location for Carters Creek. The reconnaissance sites are in green circles. Routine sites are in green triangles, and the overlap site between routine and reconnaissance (site 11782/80908) is in red.

Table 1. Routine water quality monitoring sites. Samples collected by TWRI staff

Station ID	Site Description	Lat Long Coordinates	Number of Samples Collected	
			Bacterial	Field
11782	Carters Creek @ SH 6	N 30.64407, W -96.3117	24	24
11783	Burton Creek @ SH 6	N 30.644428, W -96.13953	24	24
11785	Carters Creek @ Bird Pond Rd	N 30.602817, W -96.250027	24	24
21259	Carters Creek @ WD Fitch	N 30.588628, W -96.224594	24	24

Analysis for these sites included in-stream chemical analysis, stream flow, and collection of water samples for *E. coli* and nutrient measurements. In-stream chemical analysis included: pH, water and air temperature (º C), dissolved oxygen (mg L^{-1}), and specific conductance (µS cm^{-1}). Stream flow was measured followingfollowing USGS procedure. Total water depth and area (ft^2) were then calculated by dividing the total width of the stream (ft) into twenty equal-width sections and measuring the depth at the mid-point of each section. Instantaneous flow (ft sec^{-1}) was also taken at this mid-point; for depths in each segment of less than 0.732 m a 60% flow calculation was used. For depths greater than 0.732 m a 20/80 flow calculation was used. Instant flow for each segment was calculated by multiplying the area by the flow measured; total instantaneous flow was then calculated as the summation of the flow of all twenty sections. Field measurements were then converted to SI units. Stream flow was measured using a YSI Sonde (YSI Inc./Xylem Inc., Yellow Springs, OH, USA) and a SonTek Flow Tracker Handheld-ADV Doppler (SonTek/ Xylem Inc. Yellow Springs, OH, USA).

In addition to in-stream measurements, grab-samples were taken at each sampling location. Two grab-samples were collected with sterile whirl-pack bags (Nasco, Fort Atkinson, Wisconsin, USA) and transported on ice to Texas A&M University, one to a NELAP certified laboratory for *E. coli* analysis and one to the NaWA Lab for nutrient analysis. Samples were delivered and analyzed within six hours of collection for *E. coli* and within 20 hours of collection for nutrients.

2.2.3 Sample collection – reconnaissance water quality sampling

Because of the expense of water quality sampling by paid professionals, citizen scientist volunteers were used to collect water quality data and samples from 10 monitoring sites across the watershed (Figure 2; Table 1). Reconnaissance sites were chosen based on several criteria: a) points of interest, b) accessibility, c) historical data sets and d) their distribution throughout the watershed. General sections which reconnaissance sites were selected were based on potential sources located along that segment. Two potential sources of surface water contamination are the wastewater treatment facilities in Carters Creek watershed. Because of this, sampling sites were located upstream and downstream of the outfalls for the two WWTF in the watershed. Sampling sites 80916 and 90813 are upstream and downstream of the Carters Creek WWTF and sampling sites 80912 and 80908 are upstream and downstream of the Burton Creek WWTF. There are also several sampling sites that were selected based on perceived non-point source contributions. These sampling sites included 80917 which is located downstream of Veterans Park, a large outdoor community sports center. Specific locations of some of these sites were based on previous studies in the area conducted by (Harclerode et al. 2013) specifically sites 80910, 80915, 80911, and 80914 (Table 2; Figure 2).

Collection of physical stream samples and data at the reconnaissance sites were conducted following the Texas Stream Team volunteer monitoring sampling guidelines

Table 2 Reconnaissance monitoring sites. Samples collected by citizen scientist volunteers.

	Site Description	Lat Long Coordinates	Analysis	
			Bacteria	Chemical
80908	Burton Creek @ SH 6	N30.644428, W-96.313953	24	23
80909	Carters Creek @ Briarcrest	N30.671092, W-96.320336	24	24
80911	Bee Creek @ Appomattox	N30.609689, W-96.281514	24	23
80912	Burton Creek 65 m d/s Tanglewood	N30.640814, W-96.335192	24	23
80910	Tributary of Burton Creek @ Maloney	N30.642361, W-96.353539	24	23
80915	Briar Creek @ SH 6	N30.663617, W-96.329931	24	24
80913	Carters Creek below CCWWTF	N30.615506, W-96.268889	24	24
89016	Carters Creek above CCWWTF	N30.615175, W-96.275872	24	23
89017	Hudson Creek @ SH 30/Harvey Rd.	N30.636861, W-96.295269	24	24
89014	Wolfpen Creek @ Raintree Park	N30.622572, W-96.2911	24	24

using the Texas Stream Team water quality monitoring kit. For each sampling date, at least two volunteers were assigned to a site. Of these, at least one volunteer per site was a certified trained volunteer monitor with the Texas Stream Team. Certified volunteers have completed a four hour training course and passed the associated certification exam.

The training is to ensure that the volunteers understand the importance of following the monitoring procedure and are trained in the specific tests required of them. Volunteers collected specific water chemistry parameters including electrical conductivity (EC), dissolved oxygen (DO), pH, water transparency (through use of a secchi dish or transparency tube), water and air temperature, and stream depth. Volunteers were also responsible for field observations such as algae cover (absent, rare, common abundant, or dominant), water color (no color, light green, dark green, tan, red, green/brown, or black), water clarity (clear, cloudy, or turbid), water surface (clear, scum, foam, debris, or sheen), water odor (none, oil, acrid, sewage, rotten eggs, fishy, or musky). These field observations were used to compare the current conditions of monitoring among sites and between dates, but are not scientifically significant because of their subjective nature (variations between volunteer opinions). In addition to the Texas Stream Team monitoring protocol, volunteers' collected two water samples using sterile 200 mL whirl-pack bags (Nasco, Fort Atkinson, Wisconsin, USA). The two water samples were transported on ice, one to the WWTF within the city of the sample location for analysis of *E. coli* and the other for nutrient analysis at the Nutrient and Water Analyses (NaWA) Laboratory at Texas A&M University. Reconnaissance

samples (collected by volunteer citizen scientists and routine and storm flow samples (collected by TWRI staff) were processed in the same way by the receiving laboratories.

2.2.4 Analysis of E. coli

2.2.4.1 Routine sampling sites

Collections at the routine sample site for *E coli* were quantified using the mTEC method (USEPA Method 1603; USEPA 2000). Briefly, aliquots of stream samples were filtered through a sterile 0.45-µm Millipore filters and incubated on modified mTEC agar for 2 h at 35 °C and 22–24 h at 44.5 °C. Colonies were counted to provide a value of colony forming units per 100 mL (CFU 100 mL^{-1}).

2.2.4.2 Reconnaissance sampling sites

Collections at the reconnaissance sample sites for *E.coli* were delivered to the appropriate WWTF for their standard analysis of *E. coli*. Samples were analyzed within the 24 hour holding time non-regulatory period. *E. coli* were quantified using the IDEXX method (SM 9223-B) which rather than providing the colony forming units gives a most probable number in a sample (MPN 100 mL^{-1}). Briefly, this is a quanti-tray 2000 method which is applicable for samples containing from 1-2419 MPN 100 mL^{-1}. The sample is shaken vigorously prior to transfer of 100 mL to a measuring container where a packet of Colilert reagent is added. The container is capped and shaken until the Colilert reagent is dissolved. Once the reagent is dissolved the solution is poured into a quanti 2000 tray. The tray is sealed and incubated for 24 h at 3 ±0.5º C. A UV lamp is

used to check fluorescence in sample wells, those wells that show fluorescence are positive for *E. coli*. A table is then used to convert number of fluorescent wells to MPN 100 mL^{-1}.

2.2.5 Chemical analyses

pH and electrical conductivity were recorded on unfiltered samples. Samples were vacuum filtered through Whatman GF/F glass fiber filters (0.7 µm) prior to chemical analysis for NO_3-N, NH_4-N, PO_4-P, DOC and TDN. DOC and TDN were measured using high-temperature Pt-catalyzed combustion with a Shimadzu TOC-VCSH and Shimadzu total measuring unit TNM-1 (Shimadzu Corp. Houston, TX, USA). DOC was measured as non-purgeable carbon using USEPA method 415.1, which entails acidifying the sample and sparging for 4 minutes with C-free air. Ammonium-N was analyzed using the phenate hypochlorite method with sodium nitroprusside enhancement (USEPA method 350.1) and nitrate-N was analyzed using Cd-Cu reduction (USEPA method 353.3). Orthophosphate-P concentration was quantified using the ascorbic acid, molybdate-blue method (USEPA method 365.1). All colorimetric methods were performed with a Smartchem Discrete Analyzer (Westco Scientific Instruments Inc. Brookfield, CT, USA). DON was calculated as the difference of TDN − (NH_4-N + NO_3-N). Check standards and NIST traceable standards were run every 12th sample to test for instrument precision and accuracy.

2.2.6 Statistical analyses

All data were tested for normal distribution. As is usually the case with stream water studies, the data were skewed. To support the assumptions of parametric statistics, data were transformed to natural log prior to statistical analysis. The Shapiro-Wilks statistic test was used to verify the assumption of normal distributions on transformed data. All statistical tests were performed on transformed data. Means and standard deviations are reported for the untransformed data. Analysis of variance (ANOVA) with Site Name as the independent variable and *E. coli* or nutrients as dependent variables was performed for each nutrient in turn on a) an annual basis to compare sample years, b) seasonal basis to compare season. Post hoc Tukey tests were performed with each ANOVA. Additional two sample two tailed Student T-Tests with equal variance were performed for WWTF analysis and comparison between comparison sites for the same time period. Backwards regression analysis was used to determine if relationships between *E. coli* and nutrient concentrations might exist.

2.3 Results

2.3.1 E. coli *in Carters Creek watershed*

2.3.1.1 Routine sampling sites

Generally the downstream samples had higher *E. coli* counts compared to upstream sites as Carters Creek wound through the urbanized area of the watershed. From upstream to downstream, a two-year average geometric mean of 154 CFU (site 11782) to 591 CFU (site 11785) just downstream of the College Station area was

observed. *E. coli* CFU then decreased to a two-year average of 399 CFU at the lowest monitoring point (site 21259). Site 11783 (Burton Creek Waste Water) is the only site on Burton Creek and enters Carters Creek just below site 11782. The two-year geometric mean for site 11783 was 431 CFU with a minimum of 50 and a maximum of 4,500 CFU. Highest maximum *E. coli* was observed at Carters Creek upstream of the confluence of Burton Creek with Carters Creek which showed a maximum of 7,400 CFU 100 mL^{-1} (Table 3).

A high percentage of the samples exceeded the single sample standard of 399 CFU 100 mL^{-1} (Table 4). In Year 1, site 11785 (downstream from Burton and Carters Creek WWTF on Carters Creek) exceeded the single sample criteria 75% of the time and exceeded it 92% of the time in year 2 (Table 4). Lowest exceedance (range: 8% Year 1 to 17% Year 2) of the 399 CFU 100 mL^{-1} was observed at site 11782 (upstream of Burton and Carters Creek WWTF on Carters Creek) (Table 4).

Season had little effect on *E. coli* numbers at the routine sites (Table 5). At sites 11782 and 11783 these was no discernable season that had more or less *E. coli* counts (Table 5). At site 11785 *E. coli* counts were highest in Spring 2014 and lowest in Winter 2013 (Table 5). At site 21259, the most downstream sample of the Carters Creek basin and downstream of Carters Creek WWTF highest E. coli was observed in Winter 2014 and lowest in Summer 2013 (Table 5).

Table 3. Two-year geometric mean values for *E. coli* (CFU 100 mL^{-1}) at the routine sampling sites.

Site ID	Description	Segment	N	*E. coli* (CFU 100 mL^{-1})		
				Geomean	Range (min)	Range (max)
11782	Carter's Creek Upstream of Burton	1209C	24	154	16	7400
11783	Burton Creek Waste Water	1209L	24	431	140	4500
11785	Carter's Creek Bird Pond	1209C	24	591	253	2300
21259	Carter's Creek WD Fitch	1209C	24	399	100	1900

Table 4. Annual and two-year geometric means for *E. coli (*CFU 100 mL^{-1}) at the routine sites. Percent of individual samples exceeding 399 CFU 100 mL^{-1} during the time period at the routine sites.

Time Period		Site Number			
		11782	11783	11785	21259
		Annual Geometric Mean *E. coli* (CFU 100 mL^{-1})			
02/2013 - 01/2014	Geometric Mean	135	442	500	314
	% > 399 CFU 100 mL^{-1}	8%	50%	75%	33%
02/2014 - 02/2015	Geometric Mean	176	421	699	509
	% > 399 CFU 100 mL^{-1}	17%	33%	92%	75%
2013 - 2015	Geometric Mean	154	431	591	399
	% > 399 CFU 100 mL^{-1}	13%	42%	83%	54%

Table 5. Seasonal geometric means for *E. coli* (CFU 100 mL^{-1}) at the routine sites.

	Site Number			
	11782	11783	11785	21259
	Geometric mean *E. coli* (CFU 100 mL^{-1})			
Spring 2013	138±21	268±6	663±38	421±104
Summer 2013	131±84	570±663	394±101	156±57
Fall 2013	242±213	745±285	661±67	514±190
Winter 2013	76±31	337±208	361±200	287±178
Spring 2014	228±4239	696±2440	1035±927	532±227
Summer 2014	118±49	346±25	568±102	407±984
Fall 2014	107±87	453±95	781±71	457±166
Winter 2014	332±581	287±438	519±434	677±78

2.3.1.2 Reconnaissance sampling sites

The geometric mean most probable number (MPN) values for *E. coli* varied greatly for the reconnaissance sites (Table 6). The two-year geometric mean ranged from a low of 62 MPN 100 mL^{-1} at site 80915 (Briar Creek) to a high of 751 MPN 100 mL^{-1} at site 80913 (downstream from Carters Creek WWTF). The lowest count of *E. coli* was recorded at site 80915 (Briar Creek) with 2 MPN 100 mL^{-1} (Table 4). One of the issues with the reconnaissance sites was the method for determining *E. coli* in that the maximum that can be recorded using the IDEXX quanti-Tray 2000 method was 2419 MPN 100 mL^{-1}.

Generally for the watershed *E. coli* was elevated and above the criteria listed for the watershed (Table 4 and 7). 80915 and 11782 are very close to each other and are on the upstream portion of the watershed were the only two sites to meet the criteria (Table 4 and 7).

The primary contact recreation criteria for *E.coli* of 399 MNP 100 mL^{-1} for single samples was not met in many of the reconnaissance sites (Table 7). Site 80915 (Briar Creek a headwater tributary of Carters Creek) displayed the least exceedance of primary recreation single sample criteria with 0% exceedance in Year 1 and 33% of samples exceeding 399 MPN 100 L^{-1} in Year 2 (Table 7). Site 80913 (downstream of Carters Creek WWTF) had 92% of samples exceeding in Year 1 and 83% samples exceeding primary contact recreation criteria for a single sample in Year 2 (Table 7). Exceedance of the single sample criteria for the rest of the reconnaissance sites was in the region of 50% over the two-year sample period (Table 7).

Season had no significant effect on *E. coli* counts for the reconnaissance streams (ANOVA α 0.05). Lowest *E. coli* was observed at site 80915 during Spring 2013 and highest *E. coli* was observed at site 80912 during Summer 2014 (Table 8)

Table 6. Two-year geometric mean values for *E. coli* (MPN 100 mL^{-1}) at the reconnaissance sites.

Site ID	Description	Segment	N	*E. coli* (MPN 100 mL^{-1})		
				Geometric mean	Range (min)	Range (max)
80908	Burton Creek upstream of SH6	1209L	24	421	167	2419
80909	Carters Creek @ Briarcrest Dr.	1209C	24	223	15.8	1986
80910	Tributary on Maloney Ave	-	24	362	37.3	2419
80911	Bee Creek	-	24	242	16	2419
80912	Burton Creek d/s Tanglewood Dr	1209L	24	492	50.5	2419
80913	Carters downstream WWTF	1209C	24	751	82	2419
80914	Wolf Pen Creek	1209F	24	363	38	2419
80915	Briar Creek	-	24	62	2	2419
80916	Carters upstream WWTF	1209C	24	521	179	2419
80917	Hudson Creek	-	24	187	48	2419

Table 7. Annual and two-year geometric means for *E. coli* (MPN 100 mL^{-1}) at the reconnaissance sites. Percent samples exceeding 399 MPN 100 mL^{-1} for the reconnaissance sites included.

Time Period		Site Number									
		80908	80909	80910	80912	80915	80911	80913	80914	80916	80917
		Annual Geometric Mean *E. coli* (MPN 100 mL^{-1})									
2013	Geometric Mean	364	222	306	323	24	216	819	319	397	172
	> 399 MPN 100 mL^{-1}	25%	25%	33%	33%	0%	25%	92%	50%	67%	25%
2014	Geometric Mean	487	224	304	397	93	271	689	413	610	204
	> 399 MPN 100 mL^{-1}	75%	25%	50%	50%	33%	42%	83%	67%	67%	33%
2013 - 2014	Geometric Mean	421	223	305	358	45	242	751	363	488	187
	> 399 MPN 100 mL^{-1}	50%	25%	42%	42%	17%	33%	88%	58%	67%	29%

Table 8. Seasonal geometric means for *E. coli* (MPN 100 mL^{-1}) at the reconnaissance sites.

	Site Number									
	80908	80909	80910	80912	80915	80911	80913	80914	80916	80917
	E. coli (MPN 100 mL^{-1})									
Spring 2013	286±18	194±31	188±331	162±408	6±6	201±1110	803±151	203±41	417±85	82±76
Summer 2013	429±402	453±447	863±1317	292±320	24±52	185±152	610±445	904±522	393±179	371±360
Fall 2013	421±549	218±199	510±840	572±537	74±141	181±78	1034±723	656±365	419±177	279±238
Winter 2013	339±102	128±107	150±134	169±150	35±33	324±410	887±146	86±56	363±206	104±56
Spring 2014	486±1270	214±1062	42±24	113±97	12±20	216±1323	1151±940	742±1158	1119±1274	207±1362
Summer 2014	498±17	234±370	974±1046	1395±993	48±55	342±800	858±255	276±177	418±38	202±226
Fall 2014	470±65	130±165	515±564	262±121	171±590	141±205	1250±434	403±190	516±233	202±596
Winter 2014	496±643	386±514	211±307	601±1005	760±1073	522±1207	182±184	350±359	700±45	206±852

2.3.2 Nutrient concentrations

In total 331 samples were collected and analyzed for nutrient concentrations. A total of 336 samples should have been collected, but loss of sample by leakage during transport resulted in the loss of 5 samples over the two-year project.

2.3.2.1 Chemical constituents of stream water at the routine sites

Two-year average pH for the four routine sites ranged from 7.8±0.6 at site 11783 to 8.2±0.6 at site 21259 (Figure 3A). Electric Conductivity ranged from 433±228 µS cm^{-1} at site 11782 to 1188±236 µS cm^{-1} at site11783 (Figure 3 B). Nitrate-N concentrations were significantly higher at sites 11783, 11785 and 21259 with 2-year average concentrations of 20.1±6.3, 15.7±5.5 and 14.5±4.6 mg L^{-1} respectively (Figure 3 C). These sites were located downstream from WWTFs. The lowest 2-year average nitrate-N concentration of 1.2±2.7 mg L^{-1} was collected at site 11782 on the main stem of Carters Creek upstream of any WWTFs (Figure 3C). Mean ammonium-N concentrations for the 2 year sampling period ranged from 0.15±0.05 mg L^{-1} at site 11782 to 0.25±0.19 mg L^{-1} at site 1783 (Figure 3D). Orthophosphate-P concentrations were also significantly higher at sites downstream of WWTFs with high concentrations of 3.4±1.23, 2.9±0.96 and 2.7±0.85 mg L^{-1} from sites 11783, 11785 and 21259 respectively (Figure 3E). The lowest 2 year average PO_4-P concentration was found at site 11782 at 0.5±0.7 mg L^{-1} (Figure 3E). Dissolved organic nitrogen concentrations were low with considerable variance over the four routine sites and ranged from a low of 1.0±1.5 at site 11782 to a high of 2.7±3.05 at site 11785 (Figure 3F). There was no significant

difference in the two-year average DOC at the routine sites (Figure 4A). Two-year averages for DOC:DON ratio ranged from 20.6±24.92 11783 to 232.1±899.35 at site 21259 (Figure 4B). DON:TDN ratio ranged from 0.1±0.18 for sites 21259 and 11783 to 0.5±0.20 at site 11782 (Figure 4C). Site 11785 also had an average of 0.1 but had a wider variance (±0.19) (Figure 4C).

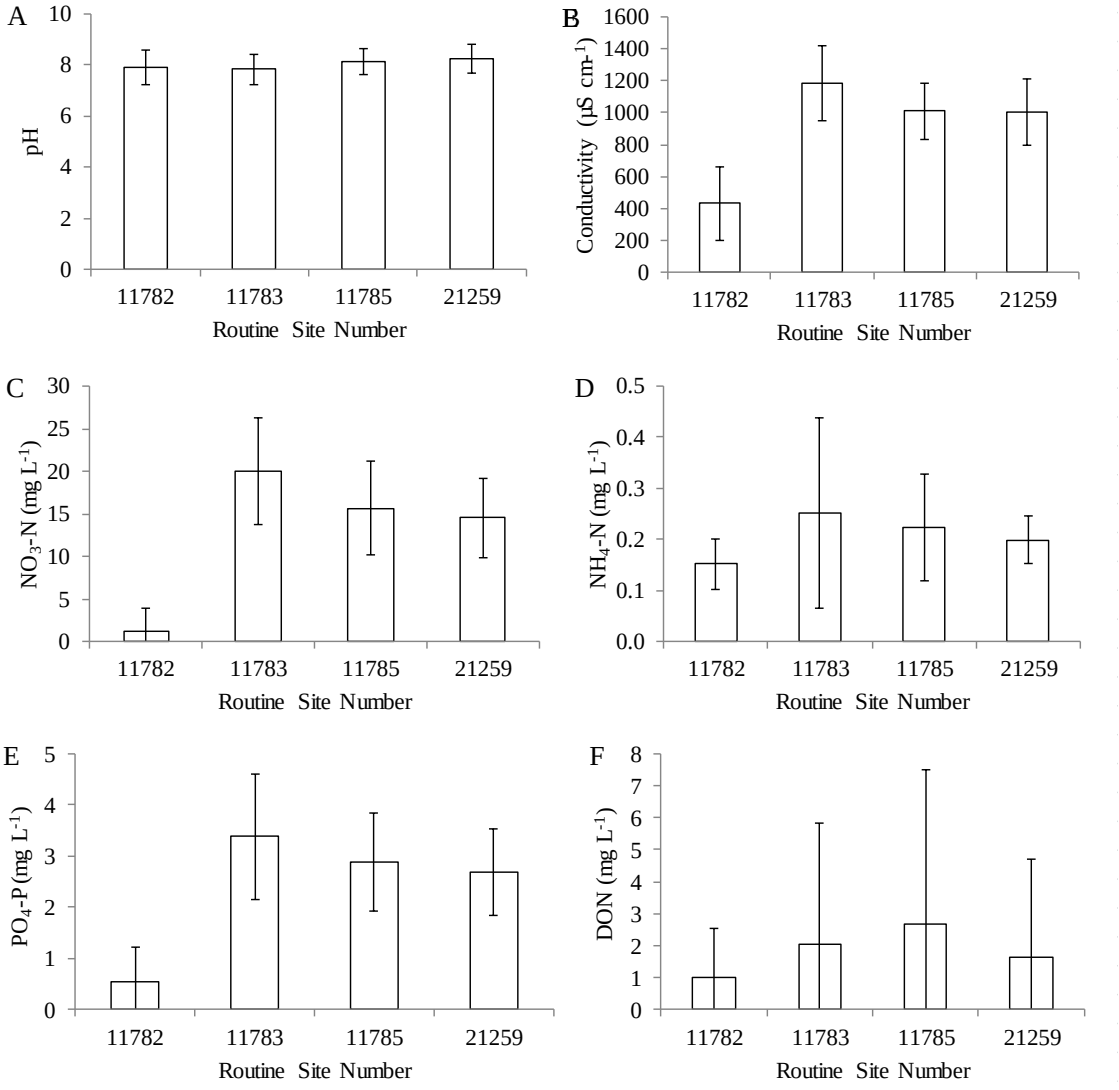

Figure 3. Mean two-year pH, conductivity and concentrations of N species and PO_4-P at the routine sample sites. Error bars are standard deviation.

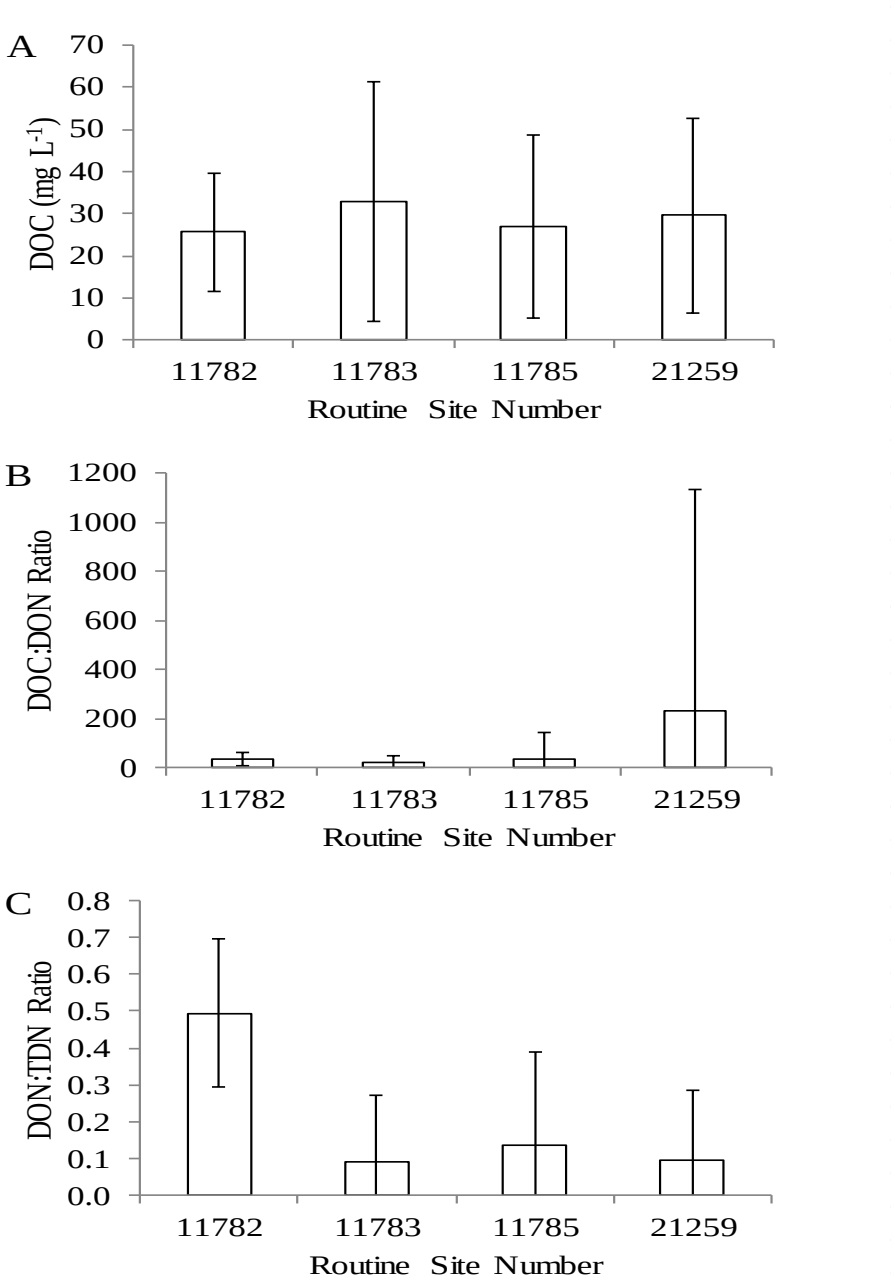

Figure 4.Two-year average dissolved organic carbon (DOC) concentrations and ratios of DOC:DON and DON:TDN for the routine sites. Error bars are standard deviation.

2.3.2.2 Chemical constituents of the reconnaissance sites

Two-year conductivity values ranged from 420±157 and 425±156 at site 80915 and 80909 to 1200±299 at site 80908 (Figure 5A). pH concentrations were very similar throughout the watershed with a minimum concentration of 7.64±0.77(site 90809) and a maximum of 8.29±0.89 (site 80912) (Figure 5B). Ammonium-N concentrations ranged from 0.14±0.04 mg L^{-1} at site 80912 to 0.25±0.21 mg L^{-1} at site 80908 (Figure 6A). Nitrate-N concentrations ranged from 0.33±0.30 mg L^{-1} at site 80910 and 19.99±6.49 mg L^{-1} at site 80908 (Figure 6B). DON ranged from 0.55±0.31 mg L^{-1} at site 80909 to 2.36±3.68 mg L^{-1} at site 80913 (Figure 6C). DOC concentrations ranged from 22.45±10.52 mg L^{-1} at site 80909 to 48.66±36.91 mg L^{-1} at site 80912 (Figure 7A). DOC:DON ratio ranged from 13.35±15.92 at site 80913 to 59.11±81.45 at site 89014 (Figure 7B). DON:TDN ratio ranged from 0.10±0.18 at 80908 to 0.64±0.28 at site 89012 (Figure 7C). Orthophosphate–P concentrations ranged from 0.30±0.16 mg L^{-1} at site 80915 to 3.48±1.09 mg L^{-1} at site 80908 (Figure 8A). TDN ranged from 1.26±0.57 mg L^{-1} (site 80911) to 22.22±5.21 mg L^{-1} at site 80908 (Figure 8B)).

There were significant differences between the means for the pH, conductivity, NH_4-N, PO_4-P, DON concentrations, the DON:TDN and DOC;DON ratios and *E. coli* counts among seasons in the watershed sub-basins.

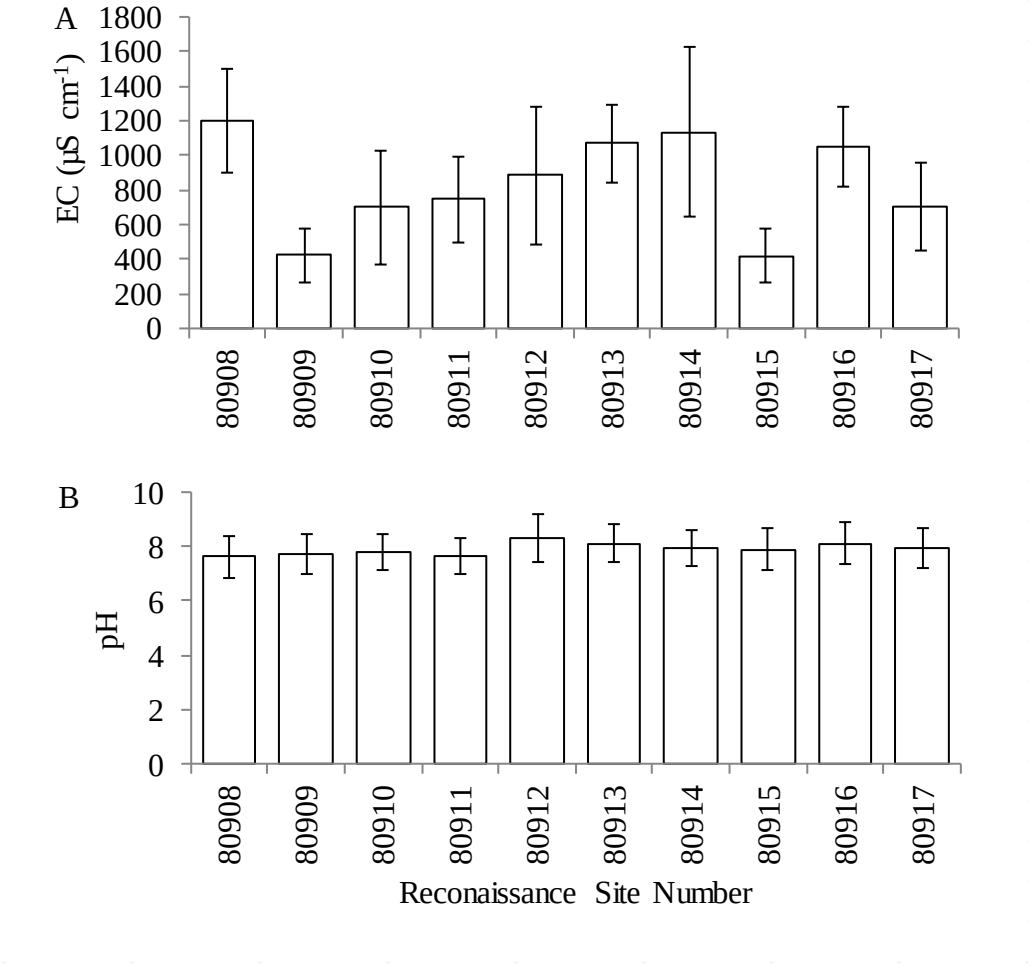

Figure 5.Two-year average electrical conductivity (EC) and pH for the reconnaissance sites. Error bars are standard deviation.

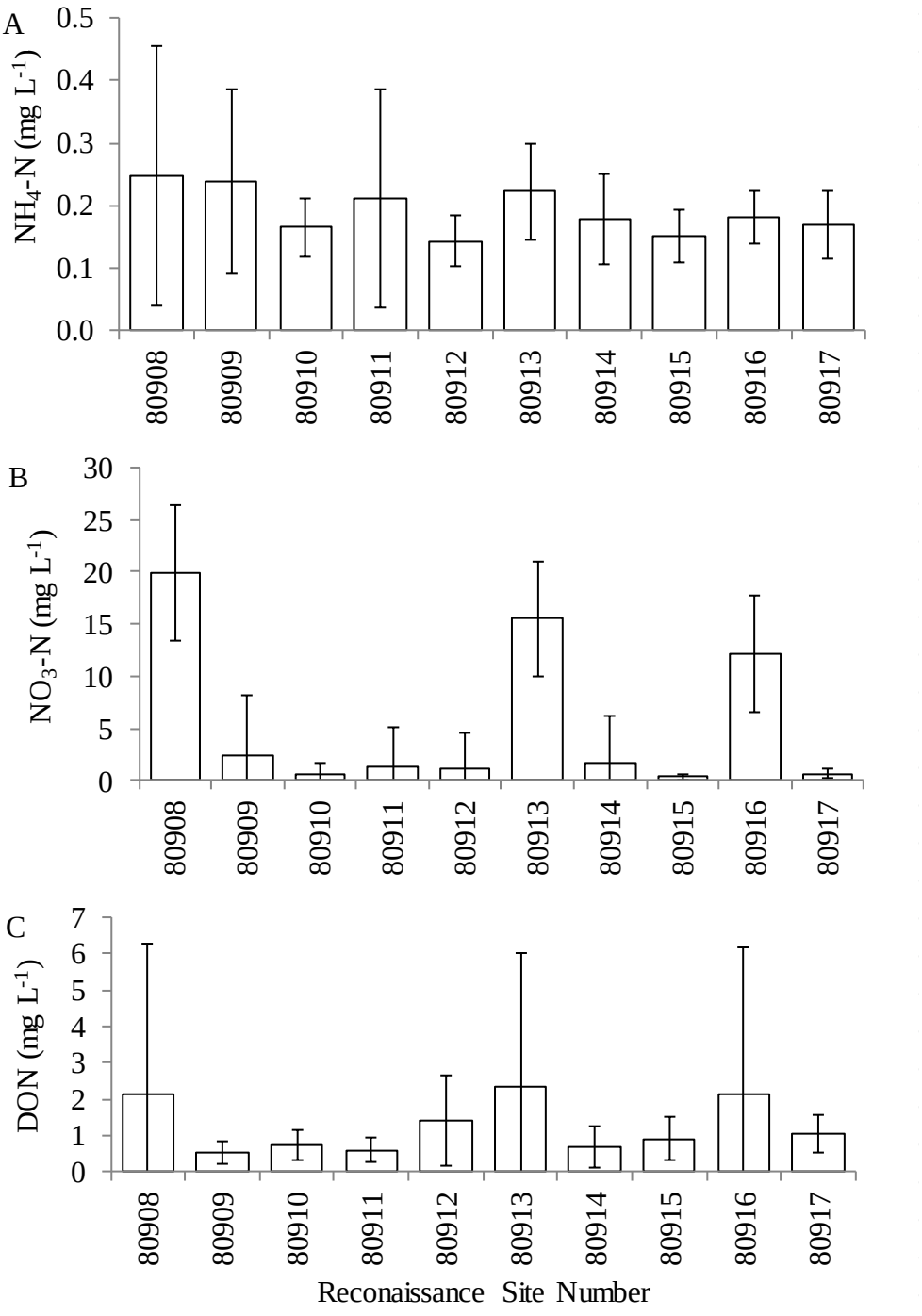

Figure 6. Two-year average NH_4-N, NO_3-N and DON for the reconnaissance sites. Error bars are standard deviation.

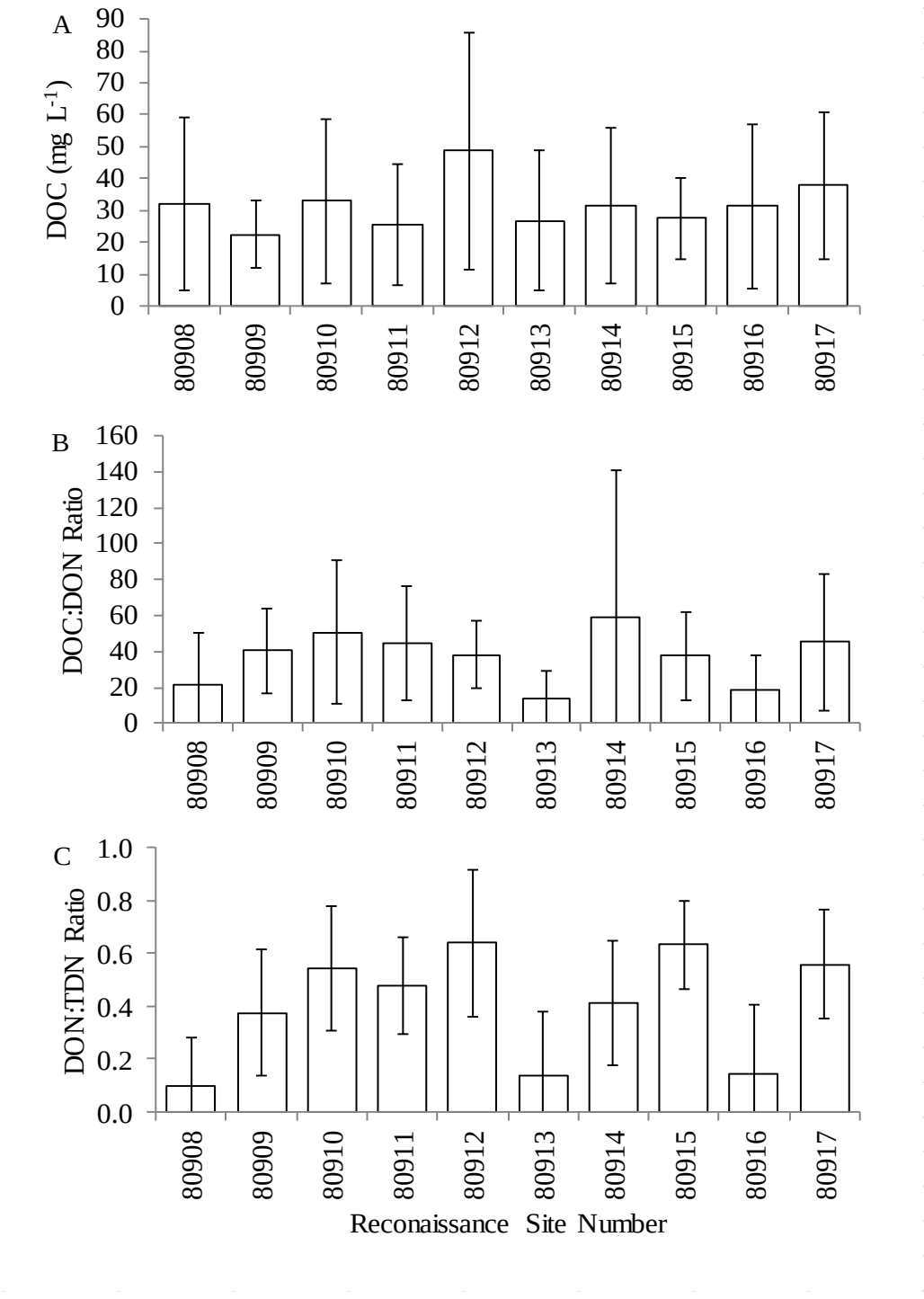

Figure 7. Two- year average DOC, DOC:DON ratio and DON:TDN ratio for the reconnaissance sites. Error bars are standard deviation.

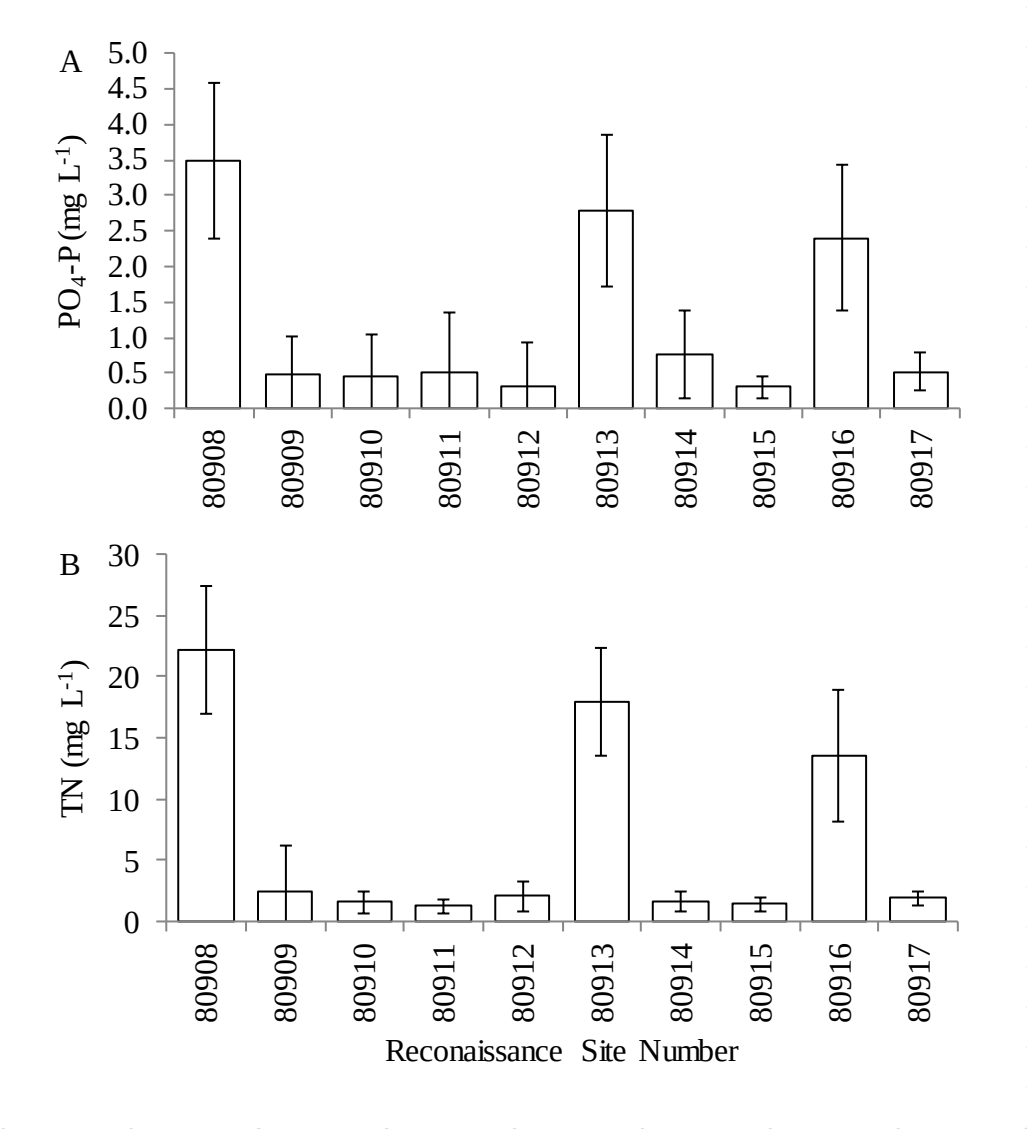

Figure 8. Two-year average PO4-P and TDN concentrations for the reconnaissance sites. Error bars are standard deviation.

2.3.2.3 Nutrient concentrations upstream and downstream of WWTF

The downstream Carters Creek WWTF (site 80913) had a statistically higher concentration for NO_3-N ($p=0.018$), NH_4-N ($p=0.017$) and TN ($p =0.001$) (Table 9). Meanwhile, the Burton Creek WWTF downstream site (80908) had significantly higher concentrations for all nutrients studied downstream except for DON and pH ($p<0.05$), which). pH experienced decrease from 8.29 to 7.64 between upstream and *E. coli* downstream sites and DON, although higher concentrations were observed downstream these were not significant(Table 9). In comparison between the two downstream sites (80913 and 80908), site 80913 had significantly higher pH concentrations ($p=0.034$) while 80908 had significantly higher nitrate-N, orthophosphate-P, TDN and *E. coli* concentrations (Table 9). Other nutrients tested did not have significantly different concentrations although the average concentrations for conductivity, ammonium-N, DOC, and DOC:DON ratio were higher for 80908 while DON and DON:TDN ratio was higher for 80913.

Table 9.Average nutrient concentrations upstream and downstream of two WWTF in the watershed and a comparison of downstream flows

		pH	Cond	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	DON:TDN Ratio	DOC:DON Ratio
			µS cm^{-1}	mg L^{-1}							
Carters Creek WWTF	Upstream (80916)	8.08	1038.80	11.84	0.18	2.36	29.47	13.22	2.15	0.15	17.99
	Downstream (80913)	8.10	1067.77	15.51	0.22	2.78	26.81	17.94	2.36	0.14	13.34
	T-Test p <	0.45	0.32	**0.02**	**0.02**	0.11	0.49	**0.00**	0.40	0.46	0.29
Burton Creek WWTF	Upstream (80912)	8.29	885.52	1.16	0.14	0.31	48.66	2.03	1.42	0.64	37.88
	Downstream (80908)	7.64	1200.61	19.99	0.25	3.48	32.05	22.22	2.13	0.10	21.38
	T-Test p <	**0.01**	**0.00**	**0.00**	**0.01**	**0.00**	**0.04**	**0.00**	0.22	**0.00**	**0.01**
Down-stream WWTF	Carters (80913)	8.10	1067.77	15.51	0.22	2.78	26.81	17.94	2.36	0.14	13.34
	Burton (80908)	7.64	1200.61	19.99	0.25	3.48	32.05	22.22	2.13	0.10	21.38
	T-Test p <	**0.03**	0.09	**0.01**	0.59	**0.03**	0.47	**0.00**	0.84	0.55	0.24

2.3.2.4 Rain event on nutrient and E. coli concentrations

For this study, rain events were counted as sample events where precipitation occurred within the preceding 3 days to the sampling event. Expectations were that concentrations of nutrients would be higher in streams because most nutrients in urban watersheds are derived from the watershed in runoff. DON was significantly higher for dry flow than with storm flow ($p=0.001$). *E. coli,* in contrast, was significantly higher in storm events ($p<0.004$). Average nutrient concentrations for the routine sites (Table 10) and for reconnaissance (Table 11) shows variation between dry and storm flow for each nutrient at each site. There were significant differences in pH ($p=0.003$), DOC ($p=0.001$), DON ($p=0.001$), and *E. coli* ($p=0.004$) concentrations with rain events. *E. coli* concentrations increased after rain events while pH, DOC, and DON decreased with rain events as an effect of dilution.

Table 10. Nutrient concentrations between rain and dry event samples for routine sites

		Site			
Nutrient Parameter	Event	11782	11783	11785	21259
Conductivity µs cm^{-1}	Dry	448.46	1210.77	1003.85	1007.69
	Storm	414.72	1161.36	1019.09	997.91
DOC:DON Ratio	Dry	38.40	22.31	56.99	79.92
	Storm	36.75	18.61	15.36	412.05
DON mg L^{-1}	Dry	1.38	2.76	4.42	2.50
	Storm	0.56	1.20	0.63	0.60
DON:TDN Ratio	Dry	0.54	0.12	0.22	0.14
	Storm	0.45	0.06	0.04	0.04
E. coli CFU $100mL^{-1}$	Dry	138	540	625	392
	Storm	917	740	713	611
NH_4-N mg L^{-1}	Dry	0.16	0.30	0.20	0.19
	Storm	0.15	0.19	0.25	0.21
NO_3-N mg L^{-1}	Dry	1.61	21.31	15.93	14.99
	Storm	0.68	18.61	15.42	13.95
DOC mg L^{-1}	Dry	27.88	37.18	33.21	33.17
	Storm	23.03	27.67	19.58	25.30
PO_4-P mg L^{-1}	Dry	0.61	3.61	3.01	2.89
	Storm	0.44	3.12	2.72	2.47
TDN mg L^{-1}	Dry	3.15	22.29	20.51	17.63
	Storm	1.38	19.71	15.58	13.96
pH	Dry	8.05	7.93	8.25	8.37
	Storm	7.76	7.70	8.01	8.08

Table 11: Nutrient concentrations between rain and dry event samples for reconnaissance sites

Nutrient Parameter	Event	80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Conductivity µs cm^{-1}	Dry	1327.27	442.86	740.83	767.69	995.38	1091.92	1145.39	424.00	1093.85	720.83
	Storm	1084.50	403.58	655.37	719.70	742.69	1039.18	1122.60	415.55	993.35	687.34
DOC:DON Ratio	Dry	33.84	42.09	45.57	49.18	36.97	12.60	63.97	34.59	18.47	41.43
	Storm	9.98	38.43	55.75	38.91	39.09	14.24	52.79	41.25	19.62	49.06
DON mg L^{-1}	Dry	3.03	0.60	0.87	0.64	1.79	3.80	0.71	1.10	3.35	1.31
	Storm	1.30	0.49	0.63	0.52	0.93	0.65	0.63	0.62	0.55	0.74
DON:TDN Ratio	Dry	0.13	0.36	0.58	0.46	0.70	0.22	0.42	0.71	0.21	0.68
	Storm	0.07	0.39	0.50	0.50	0.56	0.04	0.41	0.52	0.07	0.43
E. coli CFU 100 mL^{-1}	Dry	403	246	576	281	791	968	435	154	618	193
	Storm	682	573	1022	777	1120	831	671	673	696	604
NH_4-N mg L^{-1}	Dry	0.30	0.25	0.16	0.23	0.14	0.22	0.16	0.14	0.18	0.18
	Storm	0.20	0.23	0.17	0.18	0.14	0.23	0.20	0.16	0.18	0.16
NO_3-N mg L^{-1}	Dry	21.16	3.88	0.48	1.92	1.63	15.80	2.44	0.24	13.68	0.45
	Storm	18.92	0.77	0.78	0.43	0.56	15.16	0.80	0.46	10.13	0.92
DOC mg L^{-1}	Dry	44.06	25.09	35.80	29.88	63.46	33.29	36.84	31.64	38.29	46.64
	Storm	21.05	19.37	29.97	20.44	29.42	19.16	24.65	22.05	22.35	28.20
PO_4-P mg L^{-1}	Dry	3.92	0.60	0.55	0.73	0.40	3.04	0.83	0.32	2.71	0.53
	Storm	3.08	0.33	0.34	0.23	0.20	2.48	0.70	0.29	1.99	0.51
TDN mg L^{-1}	Dry	24.47	3.17	1.52	1.36	2.33	19.77	1.68	1.48	15.78	1.93
	Storm	20.15	1.48	1.58	1.13	1.63	15.78	1.62	1.24	10.64	1.82
pH	Dry	7.62	7.86	7.90	7.75	8.37	8.12	8.08	7.97	8.23	8.23
	Storm	7.53	7.58	7.70	7.53	8.19	8.08	7.81	7.79	7.97	7.64

2.3.3 Discharge and loading for Carters Creek watershed

2.3.3.1 Instantaneous discharge for the Carters Creek sub-watersheds

Instantaneous discharge varied depending on site. Site 21259, the furthest downstream site of our sampling sites, had a fairly constant discharge throughout the two-year study period (Figure 9D). Routine sites 11782, 11783, and 11785 displayed more variable discharge (Figure 9A-C). All sites had relatively constant discharge values for the first 6 months of sampling. Highest discharge was at the most downstream site, 21259 and had the highest two-year average discharge of 0.49±0.75 $m^3 s^{-1}$ (Table 12). Average discharge from Burton Creek (Site 11783) was 0.29±0.23 $m^3 s^{-1}$ and discharge from Carters Creek above the confluence of Burton Creek (site 11782) was 0.20±0.22 $m^3 s^{-1}$ and was the lowest average discharge observed for the sampling sites (Table 12). Site 11785, located downstream of the sites 11782 and 11783, was very close in discharge to site 11783 at 0.28±0.20 $m^3 s^{-1}$ (Table 12). There were variations in discharge by season and between years (Table 12).

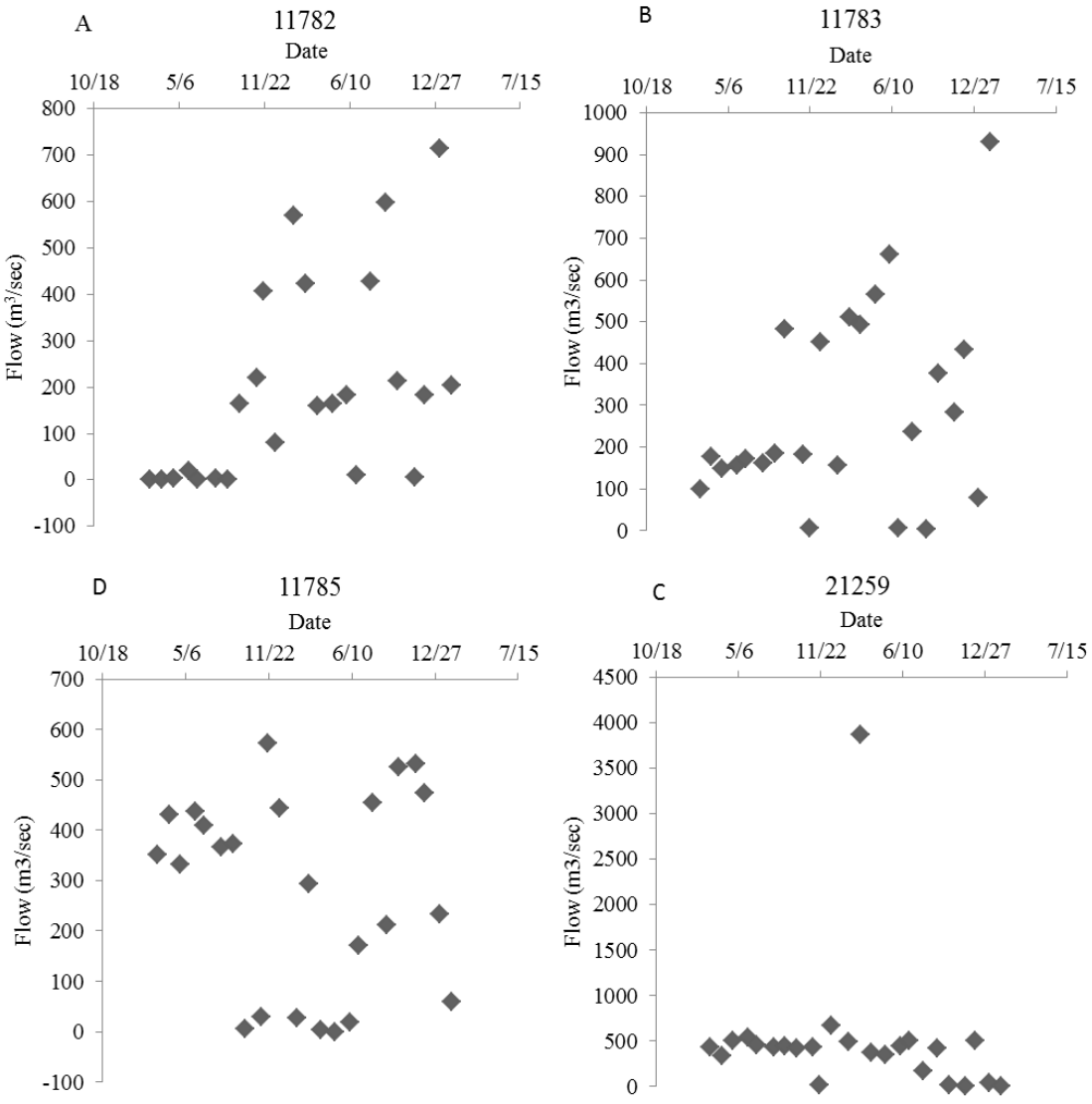

Figure 9: Instantaneous discharge measurements ($m^3 s^{-1}$) for routine sites

Table 12: Instantaneous discharge for routine sites on a seasonal, yearly, and two-year summary.

	Site Number			
	11782	11783	11785	21259
	Discharge (L s^{-1})			
Spring 2013	1.33±1.23	141.32±39.49	371.43±51.43	420.61±83.84
Summer 2013	8.25±10.94	163.22±8.16	404.91±35.98	472.36±52.86
Fall 2013	128.20±114.72	282.74±172.03	136.17±205.84	430.34±10.48
Winter 2013	352.08±249.22	205.13±226.76	348.03±284.53	392.61±342.15
Spring 2014	248.49±150.94	523.09±37.92	98.76±168.72	1531.20±2027.68
Summer 2014	206.70±210.09	300.85±331.18	214.20±221.64	372.47±175.89
Fall 2014	272.32±301.27	221.17±194.00	423.04±182.66	147.40±237.51
Winter 2014	367.50±301.42	481.03±428.31	255.30±207.80	182.34±280.36
2013 Average	122.47±188.83	198.10±134.92	315.14±187.70	428.98±154.87
2014 Average	273.75±221.33	381.54±278.13	247.83±206.84	558.35±1062.96
Two-year Average	198.11±215.53	289.82±233.41	281.48±196.20	493.67±745.80

2.3.3.2 Nutrient loads in Carters Creek sub-watersheds

Loading calculations were completed using the onsite instantaneous discharge (cf s^{-1}) which were converted to m^3 s^{-1}. Units m^3 s^{-1} were multiplied by 1,000 to achieve a discharge unit of L s^{-1}, which when multiplied by nutrient concentration (mg L^{-1})

resulted in nutrient loading at that point in time(s). Nutrient loads were extrapolated to kg d^{-1} by multiplying the instantaneous load by 84,400 (seconds in 1 day).

Site 11782, the most upstream routine site for Carters Creek had the lowest average nutrient loads of the Carters Creek sub-watersheds (Table 13), while highest average nutrient loads varied depending on site (Table 13). Site 21259 had the highest NO_3-N, NH_4-N, PO_4-P, DOC and TDN loads, while site 11783 near the confluence of Burton Creek into Carters Creek had a similar load for DON as site 21259 (Table 13).

Table 13. Daily average nutrient loads in Carters and Burton Creeks based on two-year data.

		NO_3-N kg d^{-1}	NH_4-N kg d^{-1}	PO_4-P kg d^{-1}	DOC kg d^{-1}	TDN kg d^{-1}	DON kg d^{-1}
11782	Average	11	2	7	344	24	10
	StDev	*20*	*3*	*9*	*344*	*29*	*12*
11783	Average	444	7	81	854	506	74
	StDev	*344*	*10*	*68*	*1234*	*400*	*212*
11785	Average	399	5	70	539	460	68
	StDev	*330*	*5*	*57*	*596*	*354*	*174*
21259	Average	656	8	128	1214	723	74
	StDev	*1104*	*14*	*223*	*1460*	*1204*	*145*

Seasonal nutrient loads did not differ significantly between years 2013 and 2014 (Tables 14 to 17) with the exception of Spring 2013 and Spring 2014. Loads of most nutrients were significantly lower in the Spring of 2013 when compared to Spring 2014 for routine sites 11782 and 11783 (Tables 14 and 15). At site 11785, however, nutrient loads were lower in Spring 2014 when compared to Spring 2013 (Table 16). Summer 2014 had significantly higher NO_3-N and NH_4-N loading when compared to Summer 2013 at site 22159 (Table 17). Unusual and extremely large NH_4-N loading was observed downstream of Burton Creek WWTF (site 11783) in Spring 2014 and downstream of Carters Creek WWTF (site 22159) in Winter 2013.

Table 14: Seasonal daily loads ± standard deviation for nutrients for site 11782. Difference in lower case letters indicates a significant difference between seasons in 2013 and 2014 at $\alpha<0.05$.

Site 11782	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON
Season				kg d^{-1}		
Spring 2013	0.3±0.5	0.1±0.2[a]	0.1±0.2	12±12	0.9±1.4	0.5±0.8
Summer 2013	0.3±0.4	0.02±0.04	0.1±0.1	2±4	0.4±0.7	0.2±0.3
Fall 2013	5.6±0.8	2.3±0.3	6.2±1.3	501±200	23.6±5.0	15.8±5.4
Winter 2013	28.6±33.0	2.7±1.8	8.8±8.3	607±468	49.4±47.3	18.1±15.1
Spring 2014	5.2±4.5	2.6±0.3[b]	3.9±2.0	479±287	17.4±8.6	9.7±4.4
Summer 2014	26.2±42.9	2.3±2.2	9.5±10.6	514±420	38.5±39.5	10.2±17.3
Fall 2014	11.7±13.4	3.1±3.8	10.4±8.9	420±475	32.4±38.9	17.6±21.8
Winter 2014	14.3±13.0	4.9±4.5	14.8±18.0	373±224	30.6±23.1	11.3±6.7

Table 15. Seasonal daily loads ± standard deviation for nutrients for site 11783. Difference in lower case letters indicates a significant difference between seasons in 2013 and 2014 at $\alpha<0.05$.

Site 11783	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON
Season	kg d^{-1}					
Spring 2013	300.4±97.5[a]	3.0±0.7	50.6±12.3[a]	677±432	248.6±188.4[a]	26.5±28.7
Summer 2013	357.8±33.0	4.1±1.4	64.8±4.7	179±64	407.6±68.3	45.8±37.1
Fall 2013	514.3±617.5	3.2±3.3	77.0±92.6	401±527	524.6±629.4	7.1±8.6
Winter 2013	488.3±400.0	6.0±3.7	36.5±29.7	699±310	489.2±358.3	13.0±12.2
Spring 2014	852.3±37.2[b]	31.8±28.9	204.7±12.6[b]	2818±2382	951.7±47.5	74.0±104.6
Summer 2014	194.8±227.9	5.3±6.4	95.6±91.9	1819±2519	534.0±594.5[b]	349.8±605.9
Fall 2014	352.2±300.1	6.0±6.7	62.2±54.0	254±217	375.3±319.4	17.0±19.4
Winter 2014	675.3±498.5	6.5±5.2	107.8±97.0	700±734	754.4±575.1	72.7±76.6

Table 16. Seasonal daily loads ± standard deviation for nutrients for site 11785. Difference in lower case letters indicates a significant difference between seasons in 2013 and 2014 at $\alpha<0.05$.

Site 11785	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON
Season	kg d^{-1}					
Spring 2013	686.3±104.8[a]	7.8±0.7[a]	118.1±17.6[a]	1223±993	679±148[a]	30.4±35.1
Summer 2013	579.2±57.9	12.2±9.3	103.9±5.7	350±14	739±188	147.8±142.8
Fall 2013	351.0±566.2	2.7±4.0	56.2±91.0	373±592	365±589	11.4±18.6
Winter 2013	347.0±320.6	3.3±2.6	67.0±54.1	478±419	357±312	12.9±19.9
Spring 2014	2.7±3.8[b]	0.0±0.0[b]	0.6±0.8[b]	4±5	3±4[b]	0.5±0.6
Summer 2014	291.8±362.6	3.1±2.6	57.0±70.6	778±652	269±301	8.0±13.8
Fall 2014	366.2±388.2	6.9±2.5	68.5±56.4	410±253	673±329	300.1±457.4
Winter 2014	342.8±356.6	4.7±4.2	46.3±66.7	289±247	371±382	23.7±24.3

Table 17. Seasonal daily loads ± standard deviation for nutrients for site 21259. Difference in lower case letters indicates a significant difference between individual seasons in 2013 and 2014 at $\alpha<0.05$.

Site 21259	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON
Season	kg d^{-1}					
Spring 2013	701.6±113.2	8.3±1.8	122.8±20.9	1934±1221	674±158	31.8±41.1
Summer 2013	556.7±47.0[a]	8.7±1.4[a]	106.8±9.5	441±79	721±207	156.3±165.9
Fall 2013	362.0±300.6	4.4±3.7	59.5±51.4	518±433	373±309	5.2±7.2
Winter 2013	2453.9±2768.7	27.6±37.3	490.3±567.6	2966±3040	2648±3065	181.0±251.4
Spring 2014	511.7±95.1	5.7±0.7	105.3±7.7	1655±1144	531±101	13.3±4.8
Summer 2014	171.1±105.8[b]	5.8±4.3[b]	57.2±22.4	1716±1025	328±195	165.1±285.6
Fall 2014	148.4±105.8	3.9±6.4	31.3±49.9	160±259	159±251	7.1±11.5
Winter 2014	275.4±233.4	2.5±3.7	44.4±76.1	228±358	303±492	25.3±42.8

Table 18. Estimated annual nutrient exports ± standard deviation from the routine sites. Different superscript lower case letters indicate significant difference ($\alpha < 0.05$).

Site	NO_3-N	NH_4-N	PO_4-P	NPOC	TN	DON
	kg km^{-2} yr^{-1}					
11782	112±197^{a}	21±25^{ab}	65±87^{a}	3393±3394^{ab}	231±281^{a}	99±118^{a}
11783	2893±2244^{b}	46±68^{a}	528±443^{bd}	5567±8041^{ab}	3301±2604^{b}	481±1381^{a}
11785	1215±1005^{c}	16±15^{b}	212±172^{cd}	1639±1812^{c}	1400±1078^{cd}	207±529^{a}
21259	1617±2723^{bc}	21±34^{ab}	316±550^{d}	2994±3602^{bc}	1783±2970^{bd}	182±357^{a}

2.3.3.3 Annual exports of nutrients at the routine sites

Annual exports were estimated by averaging the daily load and multiplying by 365 and dividing the value by the watershed area upstream of each sampling point. Annual exports of NO_3-N ranged from 112±197 kg km^{-2} yr^{-1} at the site upstream from WWTFs (site 11782) to 1617±2723 kg km^{-2} yr^{-1} at the site downstream of the Carters Creek WWTF. T (site 21259) here was no difference in estimated NO_3-N export when comparing sites immediately downstream of the two WWTFs ($p = 0.08$; Table 18). There was no significant increase in NO_3-N export when comparing the exports from the sample stream upstream of the WWTF to the sample site downstream of WWTF ($p = 0.50$; Table 18).)).

Annual exports of NH_4-N were 21± 25 kg km^{-2} yr^{-1} upstream of the Burton Creek WWTF and increased to 46±68 kg km^{-2} yr^{-1} downstream of Burton Creek WWTF but there was no significant difference in NH_4-N exports between the two sites ($p = 0.10$; Table 18). There was a significant decrease in NH_4-N exports between the sample site downstream of Burton Creek WWTF (site 11783) and the sample site upstream of Carters Creek WWTF (site 11785) ($p = 0.04$; Table 18).

Export of PO_4-P at site 11782 was 65±87 kg km^{-2} yr^{-1} which was significantly lower than exports downstream of the Burton Creek WWTF ($p < 0.0001$; Table 18). Export of PO_4-P decreased significantly between the sample site downstream of Burton Creek WWTF (site 11783) and site 11785 (upstream of Carters Creek WWTF ($p < 0.001$; Table 18). While there was no significant difference in PO_4-P export downstream

of the two WWTFs ($p = 0.38$), PO_4-P export was lower at the site downstream of Carters Creek WWTF (Table 18).

DOC exports ranged from1639 kg km^{-2} yr^{-1} at site 11785 to 5567 kg km^{-2} yr^{-1} at site 11783. Both WWTF downstream sites had were higher, in DOC export but not significantly higher when compared to upstream of the WWTF (Table 18). DON exports ranged from 99 to 481 kg km^{-2} yr^{-1} the highest observed at site 11783 and the lowest at site 11782 (Table 18)

2.3.4 Reconnaissance compared to routine

One site was used for both routine monitoring by water professionals as well as for reconnaissance monitoring by citizen scientists. There was an average of 3 hours difference between the times that volunteers collected their samples until the time the routine team collected their samples. Data collected were very similar between the two sampling regimes and there were no significant differences in the means (Table 19), as expected because all the chemical analyses were run by the same laboratory at the same time and using the same methods. The exercise was completed to check for a) sample contamination and b) degradation of sample during the 3 hour holding time.

2.3.5 Relationships between E. coli *and stream chemistry*

Backwards regression analysis for the individual routine sites using *E. coli* as the dependent variable and stream nutrient chemistry as independent variables was performed to assess whether stream nutrients had a significant effect on *E. coli* counts in

the routine streams. For site 11782, which is Carters Creek upstream of Burton Creek and has no known permitted discharge of effluent, 39% of the variance in *E. coli* counts was explained by stream water EC, NO_3-N, PO_4-P and DOC (Table 20). For site 11783, which is downstream of the Burton Creek WWTF, 43% of the variance in *E. coli* counts was explained by stream water EC, NO_3-N and DON (Table 20). For site 11785, which is downstream of Burton Creek WWTF and upstream of Carters Creek WWTF, there was no significant relationship between *E. coli* counts and stream chemistry (Table 20). Downstream of the Carters Creek WWTF (site 21259), 32% of the variance in *E. coli* counts was described by pH, PO_4-P DOC and DON (Table 20).

Table 19. Comparison between routine and reconnaissance teams

Site	pH	Cond	NO_3-N	NH_4-N	PO_4-P	DOC
		µS cm^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
80908	7.83±0.59	1188.13±235.83	20.07±6.28	0.25±0.18	3.39±1.23	32.82±28.46
11783	7.64±0.77	1200.61±298.73	19.99±+6.49	0.25±0.20	3.48±1.09	32.05±27.04
T-test	0.34	0.87	0.97	0.94	0.78	0.92

	TDN	DON	DON:TDN	DOC:DON	*E.coli*
	mg L^{-1}	mg L^{-1}			CFU 100 mL^{-1}
80908	21.11±6.83	2.04±3.81	0.09±0.18	20.61±24.91	420.02±882.76
11783	22.22±5.21	2.13±4.14	0.10±0.18	21.38±29.00	431.38±517.96
T-test	0.53	0.94	0.91	0.92	0.69

Table 20: Coefficients derived by backwards regression for *E. coli.* Values are estimates for the individual routine sites

Site	pH	EC	NO_3-N	PO_4-P	DOC	DON	Constant	R^2	Adj. R^2	F	*p*
		$\mu S\ cm^{-1}$			$mg\ L^{-1}$						
11782	-	9.77	-511.68	-1511.3	-64.25	-	-677.37	0.39	0.26	2.97	**0.046**
11783	-	-1.84	-49.33	-	-	-53.03	3915.98	0.43	0.35	5.07	**0.009**
11785	-	0.67	-65.33	221.88	-4.22	-34.2	582.43	0.28	0.08	1.40	0.27
21259	-132.1	-	-	-228.5	3.66	-32.09	2141.77	0.32	0.32	3.66	**0.02**

2.4. Discussion

2.4.1 E. coli *in urban watersheds*

2.4.1.1 Methods of enumerating *E. coli* for meeting standards of designated use

Impairment of surface waters by pathogens is the leading cause of surface water impairment in the USA (EPA 2004). These impairments are generally listed as bacteria as the cause of impairment on the EPA 303(d) lists for all waterbodies across the nation. *E. coli* is the typical indicator organism for the presence of pathogens in surface freshwaters (Harclerode et al. 2013). *E. coli* can be enumerated in several ways and in this study two methods were utilized, the mTEC method which produces counts of colony forming units per 100 mL (CFU 100 mL^{-1}) and the IDEXX quanti-tray 2000 method which estimates most probable numbers of *E. coli* in a 100 mL sample (MPN 100 mL^{-1}) by means of correlating fluorescent wells with a provided table. The cost of using the IDEXX method is considerably less expensive than having samples analyzed at a NELAC-certified laboratory and in essence if the *E. coli* in samples are below the Texas Commission on Environmental Quality standard for a specific designated use, then the IDEXX method works well and is the least expensive option for WWTFs to use. Designated use for Carters Creek and its sub-watersheds is primary contact recreation which has a geometric mean criteria of 126 MPN 100 mL^{-1} or a single sample criterion of 399 MPN100 mL^{-1} (Table 21). Up to 92% of the samples at the reconnaissance sites that used the IDEXX method exceeded the primary contact criterion of a single sample > 399 MPN100 mL^{-1}. Only one of the reconnaissance sites did not exceed the primary contact criterion of a single sample > 399 MPN100 mL^{-1} and that was Briar Creek.

Values for *E. coli* at Briar Creek have certainly declined since they were monitored in 2007-2008 (Harclerode et al. 2013). Harclerode et al. (2013) reported annual average *E. coli* counts of 937 MPN 100 $mL^{-1}$for low and 11,940 MPN 100 $mL^{-1}$for high flows for Briar Creek compared to a two-year average of 62 CFU 100 mL^{-1} found in this study. The Harclerode et al. (2013) sample site was upstream of the site used in this study which may have generated dilution and lower counts. Of the other sample sites, six of the sample sites exceeded the maximum grab sample more than 50% of the time. The state regulation suggests exceedance at no more than 25% of the time, which allows for streams to peak in *E. coli* counts during excessive high flow events.

Table 21. Contact recreation criteria for *E. coli* (TCEQ, 2010b).

Designated Use	Criteria Type	Criteria MPN 100 mL^{-1}
Primary Contact Recreation	Geometric Mean	126
	Single Sample	399
Secondary 1 Contact Recreation	Geometric Mean	630
Secondary 2 Contact Recreation	Geometric Mean	1030
Non-Contact Recreation	Geometric Mean	2060

Overall, this project sought to 1) develop a clearer understanding of the spatial and temporal variability in *E. coli* numbers monitored throughout the watershed, and 2) establish a clear baseline of current *E. coli* loads at a sub-watershed scale.

2.4.1.2 Effect of disinfection type on *E. coli* concentrations

The two major WWTFs were identified in the watershed as potential sources of some of the *E.coli* in the watershed. There were different organizational standard operating procedures (SOPs) between the two WWTFs in terms of disinfection of effluent prior to permitted discharge to surface water. Carters Creek WWTF used a UV light as final disinfection prior to discharging effluent into surface water, while Burton Creek WWTF used a chlorine gas disinfection system. There are advantages and disadvantages to these methods of disinfection in terms of *E. coli* recovery and regrowth. For example, Bolster et al. (2005) noted in their study on the recovery of *E. coli* after exposure to chlorine treatment that there was significant recovery three days after exposure. Their study was limited because less than the typical concentration of chlorine was used for analysis to assume worst-case scenario (Bolster et al. 2005). Furthermore, the Bolster et al. (2005) study was conducted in brackish estuarine waters. In contrast McCrary et al. (2013) saw regrowth of *E. coli* in effluent treated with UV light as soon as 6 hours after treatment and in some cases numbers exceeded primary recreation standards for *E. coli* after 12h of disinfection. Higher *E. coli* counts observed at site 80913 (downstream from the Carters Creek WWTF) might be explained by UV treatment of effluent before discharge and the assumption is that *E. coli* quickly recovered resulting in higher counts relative to site 80908 (downstream from the Burton Creek WWTF) where effluent was chlorine treated before discharge. It may be that Site 80908 is within the three day window observed by Bolster et al. (2005) resulting in lower *E. coli* counts just downstream of the WWTF, but higher counts moving

downstream. Alternatively, there may be an identifiable unidentified source of *E. coli* entering downstream of site 80909. It follows that chlorine disinfection is the better disinfectant for permitted discharges of sewage effluent but the residual chloride concentrations are likely to decline as the effluent moves downstream and is diluted. Chlorine was the industry standard because of the efficiency in disinfection, but this is no longer the case because of restrictions, permits for use, and the increasing concern of chloride toxicity to aquatic organisms and plants and riparian ecosystems when high concentrations of chloride are released (McCrary et al. 2013).

2.4.1.3 Effect of seasonality *E. coli* counts

Seasonality appeared to play a large role in increasing counts of *E. coli* and this may be simply due to high and low flow differences (i.e. Harclerode et al. 2013) indicating that the source of *E. coli* may be the watershed itself when rain events cause runoff and high flow. There were some seasonal differences in *E. coli* counts for this study in both the routine and reconnaissance sites. Much of the high rainfall occurs during the winter and spring seasons and this is generally a good indicator of the source of *E. coli*. If on the other hand the majority of high *E.coli* counts were observed during low flow, then it could be assumed that *E.coli* was derived from point sources. Permitted discharge of sewage effluent from a WWTF is a source or contribution of *E. coli* to the receiving surface water. Counts of *E. coli* from WWTF should be relatively stable but these counts will be much higher than observed for stream segments not impacted by a WWTF at low flows. In contrast, if non-point sources of *E. coli* are more

common in a watershed, then very high *E. coli* counts should be observed during high flow. High flow in this study was determined as a storm event occurring within 72 h prior to the sampling event. There was a noticeable difference between high flow and low flow *E. coli* counts at all sites except 80913 had higher *E. coli* after rain events... Some of these counts were more than double the dry condition averages. Harclerode et al. (2013) suggested that between 56 and 72% of the variance in *E. coli* in hydrologically disconnected sub watersheds of Carters Creek could be explained by the percent of urban land use during high flow conditions suggesting that the source of *E. coli* may be urban runoff.

E. coli have been reported to be viable in stream sediments at up to 60 cm depth (Brinkmeyer et al., 2015). Given the very fine material as sediment in the study streams, expectations are that while *E. coli* might be injured by disinfection, there is the potential for their recovery with favorable nutrient and environmental conditions. Further analyses of the sediment in sub-watersheds of Carters Creek basin would appear to be the next step in attempting to determine their source.

2.4.2 Nutrients in Carters Creek basin

It is difficult to determine sources of nutrients in urban streams due to the magnitude of potential sources (Walsh et al. 2005). Work by Harclerode et al. (2013) determined that there is evidence that both point and non-point sources contribute to stream nutrient concentrations. Downstream sites of the WWTFs (80908 and 80913) both showed elevated concentrations of nutrients. It is to be expected as WWTFs are a

known source of nutrient and bacteria (Divers et al. 2005). Non-point sources from urban environments also contribute considerably to surface water nutrient concentrations when inputs are more likely to be seen during rain or run-off events (Walsh et al. 2005; King et al. 2006; Kaushall et al. 2008; Characklis and Wiesner 1997). Higher concentrations for nutrients were also seen in the Carters Creek basin sub-watersheds during rain events.

2.4.2.1 Nitrate-N

Kaushall et al. (2008) suggested that during dry years nitrate is stored in watershed soils and during wet years it is flushed from the soil to surface waters after examining 1000 small watersheds with urban, agricultural and forest land use in the state of Baltimore between the years 2000 and 2004 A study by Worral et al. (2012) examined nitrate exports in the United Kingdom between 1925 and 2007 and suggested that much of the increase in nitrate export is due to land use change. The estimated nitrate-N exports at the outflow of Carters Creek basin were 2-4 times higher than reported for other studies. The combinations of contribution from WWTFs using only secondary treatment and the expansive land use change in the basin over the last 10-15 years are likely contributors to watershed nitrate-N export for Carters Creek. Production of nitrate from ammonium is an aerobic mechanism and so aerobic treatment of sewage effluent will readily convert ammonium to nitrate. Similarly, watershed soil disturbance through deforestation and land clearing will also promote nitrification of soils. However, the data reported in the current study did not support the notion that drier spells will lead to

NO_3-N retention and wetter spells will lead to NO_3-N flushing as postulated by Kaushall et al. (2008). This may be because of the volume of irrigation water used in the Carters Creek basin sub-divisions resulting in moister soils year round than would be found in Baltimore.

Nitrate-N export in the outflow of Carters Creek (site 21259) was 1617 kg km^{-2} y^{-1}) and was within the range of NO_3-N export in other urban streams (Table 22). Typically reported NO_3-N export from urban streams ranged 34 kg km^{-2} y^{-1} from a 42% urbanized stream near Perth, Australia to 3330 kg km^{-2} y^{-1} from Carroll Park watershed with 76% urbanization (Table 22).

2.4.2.2 Ammonium-N

High ammonium-N concentrations in surface waters are unusual and generally suggest that raw, untreated sewage is making its way to the stream (Bhatt et al. 2013). Two incidences of unusually high loading occurred downstream of the two WWTFs. During the winter of 2013, the routine site downstream of Carters Creek WWTF displayed very high NH_4-N loading and during the spring of 2014, the routine site downstream of Burton Creek WWTF displayed very high NH_4-N loading. This may suggest release of raw sewage at these plants during extreme rain events or may simply be due to extremely high water discharge during these months which would increase NH_4-N loads.

Exports of NH_4-N from other urban watersheds ranged from 1 kg km^{-2} y^{-1} in a watershed with 42% urbanization near Perth, Australia to 81 kg km^{-2} y^{-1} from a

watershed with 98% urbanization near Perth, Australia (Table 22). Carters Creek NH_4-N export was 21 kg km^{-2} y^{-1}, which was within the range of export for other urban streams.

2.4.2.3 Orthophosphate-P

Legacy phosphorus a current 'hot issue' for surface waters in watersheds that were once used for agriculture or grazing and is postulated as the major reason for lake eutrophication (Reddy et al. 2011). While PO_4-P concentrations, loading and export tended to be higher downstream of WWTFs in the current study, and 2 orders of magnitude higher than comparable urban streams globally (Table 22), the contribution for Carters Creek basin could primarily be from discharged effluent with other sources of PO_4-P derived from eroded soil loaded high in legacy P. The eroded soil could be derived from construction runoff associated with recent population growth in the Carters Creek basin. Other sources of PO_4-P are likely linked to the high SAR irrigation water (potable and effluent) used in the watershed that has been shown to increase PO_4-P losses from soil (Steele and Aitkenhead-Peterson 2012). In fact, as the exchangeable sodium percentage in irrigation water increases, loss of PO_4-P from soil increases (Steele and Aitkenhead-Peterson 2012).

Duan and Kaushall (2013) suggested that as air and surface water temperatures increase (to approximately 35° C), release of PO_4 from stream sediment to the water column would increase exponentially contributing 20 mg m^{-2} d^{-1} (7,300 kg km^{-2} y^{-1}) soluble reactive phosphorus to the water column in a stream such as the Dead Run, a

87% urbanized watershed in Baltimore. In Carters Creek, no increase in PO_4-P export with temperature was observed.

2.4.2.4 DOC and DON

Dissolved organic carbon and nitrogen concentrations and exports have largely been ignored for urban watersheds yet their potential contribution to *E. coli* recovery and regrowth downstream from WWTFs cannot be denied (McCrary et al. 2013; this study). Sources of DOC and DON tend to be derived from non-point sources because the secondary treatment used in the two WWTFs in this study to reduce biological oxygen demand (BOD) in essence reduces the concentrations of DOC and DON considerably. Wastewater treatment plants are postulated as a major source of DOC in urban streams in Arizona with effluent dominated streams producing DOC concentrations ranging 3.2–8.6 mg C L^{-1} (Westerhoff and Anning 2000). On the contrary, in Carters Creek and other local watersheds there was no significant difference in DOC concentrations between streams downstream of a WWTF and streams with no WWTF (Aitkenhead-Peterson et al. 2009).

In terms of non-point sources of DOC to Carters Creek basin, Aitkenhead-Peterson and Cioce (2013) and Cioce and Aitkenhead-Peterson (2015) examined abiotic and biotic controls in watershed soils. They reported that in the most urbanized watershed soils that DOC was not being adsorped by soil minerals and the release of DOC from soils was much higher from urban lawns and green space when compared to remnant, undeveloped areas of shrub and scrub (Aitkenhead-Peterson and Cioce 2013).

Furthermore the biotic control on DOC, or DOC mineralization by soil bacteria, was considerably less in soils of urban lawns and green space when compared to soils of remnant, undeveloped areas of shrub and scrub (Cioce and Aitkenhead-Peterson 2015). These abiotic and biotic controls on DOC in the Carters Creek basin induce much higher loading and export of DOC from watershed soils than would be expected from other urban watersheds

Much of the work on DOC and DON concentrations in the Carters Creek basin has focused on the effect of the high sodium adsorption (SAR) ratio of the potable water to the cities of Bryan and College Station which is derived from the Carrizo Wilcox aquifer (Aitkenhead-Peterson et al. 2011). In-ground irrigation systems deliver this high potable or effluent SAR water (SAR = 22-34) to urban green space, which induces runoff of DOC and DON. The SAR of discharged effluent at the Carters Creek WWTF was 22.6 in 2009 (Aitkenhead-Peterson et al. 2009). Streams in the Carters Creek basin have a SAR hovering around 20 (Steele and Aitkenhead-Peterson 2013). High instream SAR was found to induce enhanced release of DOC from riparian and post oak litter further contributing to high DOC concentrations in Carters Creek sub-watersheds (Steele and Aitkenhead-Peterson 2013). Export of DOC and DON for Carters Creek was 2994 and 182 kg km^{-2} y^{-1} respectively and was higher but similar to other urban streams with reported DOC and DON exports (Table 22).

Table 22. Comparison of exports of DOC, DON and nutrients in urban streams

Site		% Urban	DOC	DON	NH_4-N	NO_3-N	PO_4-P	
			kg km-2 yr-1					
Carters Creek	College Station, TX, USA	48	2,994	182	21	1617	316	This study
Bennett Brook	Perth Australia	42	994	42	1	34	1	Petrone 2010
Yule Brook	Perth Australia	36	968	62	8	87	4	Petrone 2010
Bayswater Drain	Perth Australia	98	2,241	115	81	93	1	Petrone 2010
Upper Trinity	Dallas, TX, USA	57	2,763	126	70	2654	-	Aitkenhead-Peterson et al. 2015
Dead Run	Baltimore, MD, USA	87	-	-	-	2390	6	Kaushall et al. 2008; Duan et al. 2012
Carroll Park	Baltimore, MD, USA	76	-	-	-	3330	9	Kaushall et al. 2008; Duan et al. 2012
Wilz	Poland	3	-	-	-	3170	25	Salvia-Castellvi et al. 2005
Maumee	Waterville,OH, USA	1.2	-	-	-	-	20	Baker and Richards 2002

2.4.2.5 DON:TDN Ratios

Generally a low DON:TDN ratio is indicative of anthropogenic inputs of inorganic N to surface waters whereas a high DON:TDN ratio is indicative of a relatively unimpaired watershed ecosystem (Pellerin et al. 2006). In 2007-2008, Aitkenhead-Peterson et al. (2009) examined Carters Creek sub-watersheds and reported DON:TDN ratios of 0.13-0.24 in streams downstream of a WWTF and ratios of 0.63-0.81 in streams without a WWTP. The DON:TDN ratios in this study ranged from 0.09 in the routine sites downstream of a WWTF to 0.50 at site 11782 upstream of Burton Creek WWTF. There is no doubt examining these ratios that the water quality of Carters Creek has declined during the 6 year period between sampling efforts. Much of this is likely due to the large population growth and concomitant construction of sub-division housing and associated infrastructure during this time period. There was a 36% increase in the population of College Station and a 16.5% in the population of Bryan between 2000 and 2010. Expectations and observations suggest that the two cities within Carters Creek watershed are on a similar population growth trajectory between 2010 and 2020.

2.4.3 E.coli *and nutrients relationships in Carters Creek basin*

Studies have promoted the idea that high flow in flashy 1st and 2nd order urban streams disturbs the stream substrate sediment where naturalized *E. coli* reside rendering them available in the water column for sampling (Cho et al. 2010). *E. coli* have been reported to be viable in stream sediments at up to 60 cm depth (Brinkmeyer at l. (2015). While there was no inter-annual variability in the counts of *E. coli* in stream

sediment in Houston Bayous there was a slight correlation with moisture content of the sediment and no correlation with the percent of organic matter in the sediment (Brinkmeyer et al. 2015). There was however a high correlation between *E. coli* and sediment size with between 76-87% of *E. coli* being associated with fine sand grains (Brinkmeyer et al. 2015). Cho et al., (2010) examined re-suspension of stream sediments and its attached *E. coli* at an experimental watershed in Maryland, USA. Upon releasing 80 m^3 of water into the stream channel at a rate of 60 L s^{-1} *E. coli* was re-suspended into the water column. Numbers of *E. coli* re-suspended were linked to the sediment size to which *E. coli* re attached. The average discharge in the Carter Creek routine sites was an order of magnitude higher than discharge reported by Cho et al. (2010). Individual high flow event discharge reached 600 L s^{-1} in September 2014 for site 11782, 931 L s^{-1} in February 2015 for site 11783, 572 L s^{-1} in November 2013 at site 11785 and 3872 L s^{-1} in February 2014 at site 22159. Given the very fine material as sediment in the streams of the current study, expectations are that while *E. coli* might be injured by disinfection there is the potential for their recovery given the right nutrient conditions. *E. coli* then may become naturalized in stream sediments and appear in very high numbers in the water column due to scouring of stream sediment during high flows.

Another issue is cause and effect on *E. coli* recovery. For example, the nutrients describing variance in *E. coli* numbers were different for each site and different to those reported by McCrary et a. (2013) suggesting that nutrients *per se* are not aiding recovery and regrowth but rather these specific nutrients have the same source as *E. coli*, in the sediment and are re-suspended during higher flows. Examination of the sediment for

nutrients and *E. coli* in sub-watersheds of Carters Creek basin would appear to be the next step in attempting to solve likely sources of *E. coli*.

Quite often a cause and effect of nutrients on *E. coli* counts is assumed when in fact they simply have a similar source. The work by McCrary et al. (2013) however, under controlled laboratory conditions, examined the effect of nutrients, specifically the vegetation source of DOC on *E. coli* recovery and regrowth and showed that nutrients had a positive effect on recovery and regrowth. They further applied nutrient data from the Harclerode et al. (2013) study to *E coli* counts downstream of waste water treatment plants in Carters Creek basin successfully predicting *E. coli* counts at high flows based on nutrient concentrations. McCrary et al. (2013) reported that downstream of Burton Creek WWTF nutrients PO_4-P, NH_4-N and NO_3-N explained 82% of the variance in *E. coli* counts during high flow and nutrients DOC, DON, PO_4-P and NO_3-N explained 96% of the variance in *E. coli* counts downstream of Carters Creek WWTF during high flow. While nutrient concentrations in the current study were only able to explain 43% and 32% of the variability in *E. coli* counts at these same sites, the data for high and low flow were combined. It should also be noted to that the same nutrients identified by McCrary et al. (2013) as predictors of *E. coli* counts downstream of WWTFs were not exactly the same as the current study and may be due to the a) the conversion of concentration (mg L^{-1}) to mM or b) a defined source of certain nutrients, specifically low molecular weight organic C and N compounds during high flow or c) the molar ratio of C, N and P differs between high and low flows.

Overall, considerable quantities of data were collected in this two-year study, which included measures of dissolved oxygen and turbidity. More work will be carried out in the Carters Creek basin to assess potential sources of *E. coli*. All the alternative hypotheses tested in this study failed to be rejected.

2.5. Conclusions

Conclusions for the study are as follows:

- There were *E. coli* exceedances for the designated use of the watershed. Both point and non-point sources appear to be contributing to *E.coli* concentrations in the watershed.
- WWTFs appear to be contributing to the water quality impairments in the Carters Creek basin specifically with regard to *E. coli* and nutrient (NO_3-N and PO_4-P) concentration, loading and export.
- Wet flows induced higher counts of *E. coli* compared to dry flows, but the inverse occurred with nutrient concentrations, which tended to have lower concentration during wet flows through dilution.
- While increase concentrations of nutrients were seen downstream of WWTF, there were also increased nutrient concentrations following storm events.
- Weak correlations between Weak but significant relationships among *E. coli* and nutrients were observed in the study, and more research is needed to better define these relationships determine whether the relationships are real or that cause and effect is simply a similar source for *E. coli* and nutrients.

3 NOVEL SOURCES OF NUTRIENTS IN WATERSHED SOILS

3.1 Introduction

The general consensus for enhanced nutrient concentrations in surface waters is excess fertilizer application. While this may be true in particular for agricultural watersheds, there may be other reasons for surface water nutrient enhancement in urban watersheds (Chapter 2). One source of nutrients to urban surface waters may be the transport of mammal decomposition products (Aitkenhead-Peterson et al. 2012; Wozniak et al. 2015). Animal decomposition is an important aspect of many of the nutrient cycles (Barton et al. 2013) yet is often neglected. Decomposition of dead animals allows for a relatively fast incorporation of the nutrients tied up in the organism back into the environment (Macdonald et al. 2014). The contribution of carbon, nitrogen and phosphorus derived from the decomposition of mammals such as road kill (dogs, cats, deer and skunks) and buried pets (dogs and cats) in urban watersheds has not been thoroughly examined from an ecological standpoint.

Taphonomy, the study of decomposition and nutrient flow, is a branch of anthropology that focuses specifically on the processes and variables of death and decomposition. Currently, the majority of the research available in the field focuses on forensics to aid criminal investigations. There has been a trend in this research in using the natural occurring compounds in the decomposition process to help identify clandestine graves (Aitkenhead-Peterson et al. 2012), as well as to attempt to determine postmortem intervals of cadavers (Aitkenhead-Peterson et al. 2015) and train human

remains detection (HRD) dogs (Alexander et al. 2015). Cadavers release carbon, nitrogen and phosphorus compounds to the soil as part of the decomposition process and these compounds may persist in the soil environment for months to years (Towne 2000; Brathen et al. 2002; Aitkenhead-Peterson et al. 2012, 2015). The potential for decomposition product C, N and P to affect local water quality through transport off site is under-researched.

There are many reasons why there is a lack of research on the potential effects of animal decomposition on water quality. One reason may be the difficulties that arise when it comes to replication due to variability within the same animal species. Even within the same soil series, same research methods and same animal species, variation in decomposition rates are still apparent to the point that it affects the ability to duplicate the experimental results even within a single experiment (Tumer et al. 2013).

Because of the lack of this type of research, the impact that animal decomposition may have on surface water quality is unknown. Popular press articles however indicate that unsafe disposal methods of dead hogs resulting from the porcine epidemic diarrhea (PED) virus resulted in nutrients from the decomposition of dead hogs making their way to surface waters (EcoWatch 2014). One recent study at a human donor facility in Texas, USA recognized the potential of nutrient transport from decomposing cadavers to surface waters (Wozniak et al. 2015). The Wozniak et al. (2015) study examined nutrients in surface water downslope from the facility and in retention basins designed to capture and cycle transported nutrients from the facility. They reported that nitrite and chloride concentrations were significantly higher down slope of the facility compared to

concentrations in the retention basins. Furthermore, total P was significantly higher in the retention basin compared to down slope of the facility. Unfortunately, surface water nutrients in the stream upstream of the facility were not quantified because the stream was dry during sampling and so no conjecture on the effect of the facility on surface water quality was made (Wozniak et al. 2015). Aitkenhead-Peterson et al. (2012) noted at the same facility that water extractable soil DOC, DON, PO_4-P and K^+ were significantly higher down slope of the facility and called for more research into the transport and potential contribution of animal decomposition products to surface water nutrients.

3.1.1 Variables to decomposition

There are a wide variety of variables that affect decomposition, and the interactions between these variables are still not fully understood. However, the variables can be divided into three major categories: the immediate environment (soil, temperature, and humidity), the biological community (specifically, the processes present during the decomposition process), and the condition and state of the cadaver (skin condition (autopsied, wounded), clothed or unclothed, diet, body mass index (BMI), medications taken, and species of cadaver).

Soil provides many different variables that may affect decomposition rates including its native pH, microbial communities, soil moisture content, texture, and temperature. While soil is regarded as an important factor in decomposition, Tumer et al. (2013) focused on the effects that different soil series had on the decomposition rates of

cadavers. While both soil biochemistry and texture were important, there was variation seen in decomposition rates within duplicates of the study (Tumer et al. 2013). This highlights the multivariable aspect of decomposition studies, and the difficulties there are in determining the exact contributions that specific factors may deliver to the equation.

Many different factors affect the speed of cadaver decomposition; these include the mass of the cadaver, its condition, microbiological activity, environmental conditions (available moisture, temperature), and location specific conditions (soil chemistry, soil type) (Meyer 2013; Tumer et al. 2013). Because of the large amount of microbial actions that need to take place in the beginning stages of decomposition, temperature can greatly affect the speed that the first stages of decomposition occur in and, therefore, the timing of the release of nutrients (Meyer 2013). If conditions are favorable, 75% of the body mass of a large cadaver can be recycled within 7 days (Meyer 2013). Covering of the cadaver affects the formation of adipocere, a mostly fat based, solid, waxy substance. Adipocere slows the incorporation of nutrients to plants and may reduce microbial uptake for years (Forbes 2004). Fat and water have a well-known relationship, and their interaction with each other, as well as the location of the cadaver, could be a deciding factor between more offsite movement of the adipose tissue and trapped nutrients within adipocere than normal, and no movement at all. Therefore, the factors leading to the formation of adipocere are important to understand. There is an interesting relationship between the types of covering and the formation of adipocere. Direct contact to soil caused the largest formation of adipocere when compared to coffins; however, if the

cadaver is wrapped in synthetic materials, it is found that this will lead to more adipocere formation (Forbes 2004; Meyer 2013).

3.1.2 Effects on the surrounding environment

It is well documented that decomposition causes a release into the environment of different nutrients and other broken down chemicals from the cadaver (Vass et al. 1992; Aitkenhead-Peterson 2012, 2015). However, very little research has been performed examining the environmental impacts of released decomposition products and whether these decomposition products could affect local water quality.

When cadavers are left to decompose on the soil surface a Cadaver Decomposition Island (CDI) is created (Carter et al. 2008). The CDI can be considered an area of extremely high fertility and will spread to an area of approximately 4X the area of the cadaver and to a depth of approximately 15 cm depending on soil texture. Changes in pH and conductivity have been observed in all of the studies conducted (Vass et al. 1992; Towne 2000; Brathen et al. 2002; Aitkenhead-Peterson et al. 2012). While the CDI represent a large increase in fertility in the soil, an initial observation is the death or decline in surface vegetation (Carter et al. 2008). This is observed even though the CDI provides a surplus of all nutrients needed for plant survival. The sudden death of the vegetation in the area surrounding the cadaver is due to a) a large increase in traffic caused by the scavenger and b) purge of organic acids into the surrounding soil. The dead vegetation then decomposes, adding to the nutrients in the CDI. While these enhanced nutrients will eventually contribute to the reestablishment of vegetation, there

is also a high likelihood that nutrients will runoff, especially in the absence of plant uptake. Studies have shown that DOC, DON and orthophosphate-P are mobile in the soil profile and will move beyond the boundary of the CDI (Aitkenhead-Peterson et al. 2012). Studies in different environments have demonstrated that there is a lasting effect, especially of large cadavers on the soil and, therefore, also the vegetation in the surrounding areas (Benninger 2008).

Different cadaveric tissues contribute different decomposition products. Carrion, or the muscular cellular structure, is a large source of nitrogen through NH_4 deposits and a contributor of proteins and amino acids into the soil. These are digested by cadaver microbes and then excreted into the soil environment (MacDonald 2014). MacDonald (2014) reported significant and lasting effects of large vertebrate carcass decomposition which caused large inputs of N, C, P, altered pH, and salinity to be added to a localized area.

The number of cadavers located in an area can, understandably, affect the decomposition process and the release of decomposition products into the environment. In a study focusing on human mass graves in South Africa, elevated metal concentrations were found although the concentrations were not high enough to cause human or ecological concern (Amuno 2013). In addition to increased concentrations of specific products due to the increase in cadaveric sources, there can also be a noticeable effect on the decomposition process itself. In a study of mass graves, this time using rabbits, there were different time scales of decomposition; the time for decomposition was seen to be dependent on the location of the cadaver in the grave (Troutman 2014).

Cadavers at shallower depths decomposed faster than those in the deeper depths, due to the lower availability of oxygen at the deeper depths (Troutman 2014). A feathered edge effect, where decomposition is first seen on the edges of the cadaver was also reported by Troutman (2014). This may be important from a water quality standpoint because it implies that movement of decomposition products from a mass grave would slowly be released into the environment. This could further explain the difficulty in assessing whether mass graves are sources of water quality impairment, due to the time disconnect between the typical decomposition timeline.

The specific species of the cadaver also affects the types of chemicals that are released. Stokes (2013) compared the decomposition of several domestic animals for use as human cadaver analogues. He recorded differences among human, pig, beef and dog cadavers in variables such as muscular tissue decomposition time, and chemically (pH and conductivity).

The objective of this study was to determine if animal decomposition products, specifically DOC, TDN, NH_4-N, NO_3-N and PO_4-P were transported downslope of buried pets and thus a potential source of nutrients to surface waters. Expectations were that there would be significantly higher concentrations of nutrients and DOC in soil solution and water extractable soil downslope of graves containing buried dogs compared to empty graves. This study was devised to simulate home burials of companion animals and further to quantify over a period of one year how nutrients downslope might change because of grave sites.

Specific hypothesis for this study were:

H_0: There will be no significant difference in DOC and nutrient concentrations down slope of fake graves (controls) and graves containing buried dogs in either soil solution or soil extracts.

H_1: There will be significantly higher concentrations of nutrients and DOC in soil solution and soil extracts down slope of graves containing buried dogs compared to control graves.

3.2 Materials and methods

3.2.1 Site description

The study site was located at the Urban Ecology Field Laboratory at Texas A&M University. The site was selected based on ease of access and permission given for the research. It is a natural grassland field, which was used for dairy animal grazing prior to the study. The soil at the site is a Booneville Series (fine, smectitic, thermic, chromic vertic Albaqualf). These soils typically consist of 0 – 43cm of a fine sandy loam over a clay pan. This was ideal for the project, as it would allow for nutrients to travel through the sandy loam and minimize infiltration below the cadaver. The climate is humid subtropical, with a mean annual temperature of 20°C and an annual average precipitation of 1,000 mm (Aitkenhead-Peterson et al., 2009). The site has a slope of approximately 3% downslope of the grave sites and 1% adjacent to the graves.

Figure 10. Experimental design of the pet cemetery. Site was designed to assess animal decomposition product transportation offsite. The orange oblongs depict three buried pets, while the green oblongs depict three fake graves. Orange and green circles depict positioning of lysimeters and regions of soil sampling for soil extracts.

Distance Grouping	Control Graves							Experimental Graves								
0 m	LC 1	C1	LC2	C2	LC3	C3	LC4	LB1	B1	LB2	B2	LB3	B3	LB4	LB5 -3	LB6-9
1 m		C1-1		C2-1		C3-1			B1-1		B2-1		B3-1			
			C12 R - 1.5		C23 R - 1.5					B12 R - 1.5		B23 R - 1.5			Legend	
3 m		C1-3				C3-3			B1-3				B3-3		Graves	
			C12 R - 4.5		C23 R - 4.5					B12 R - 4.5		B23 R - 4.5			Lysimeter	
7 m				C2-7							B2-7					
		C1-9				C3-9			B1-9				B3-9			
14 m				C2-13							B2-13					
		C1-14				C3-14			B1-14				B3-14			

Figure 11: Graphical layout of the lysimeter location in relationship to the grave sites. Site names are designated first by the gravesite column, and then by the measured distance in meters from the center of the grave. Lysimeter locations, depicted with an L, designate a grave-line site; lysimeters were placed in line with the center of the graves.

3.2.2 Experimental design

Three deceased dogs were donated for this research. Two of the dogs weighed 22.68 kg, while the remaining dog weighed 24.95 kg. Each dog was a different breed: 1) Australian Cattle Dog, 2) Dalmatian, and 3) Golden Labrador. Diet and cause of death of the cadavers was unknown. Six graves 60 cm x 60 cm were excavated to a depth of 50-60 cm on February 21st 2014. Removed soil was placed on a tarpaulin next to the excavated holes to ensure all soil was returned to its corresponding hole. Three of the graves contained no cadaver, while the other three graves contained 1 cadaver each. Distance between each grave was 1 m and between control experimental grave sections, 2 m. A 60 x 60 cm square metal plate (1.5 mm thickness) was inserted between the fake graves and the real graves to prevent lateral transport from the control graves to the experimental graves. Cadavers were placed on February 26th, 2014, and the graves were immediately refilled (Figure 10). To prohibit interference of the grave sites by scavengers, a thick wire mesh was placed on top of all of the graves (control and experimental), and a tarpaulin fence was constructed around the experimental graves. Lysimeters (Soil Moisture Corp, Santa Barbra, CA, USA) were installed on March 11th 2014. Two sizes of lysimeters were used; 20 that collected soil solution at 15 cm, and 20 that collected soil solution at 30 cm. Lysimeters were placed between and immediately downslope (~0.30 m) of each grave site. Additional lysimeters were then placed a varying distances down-slope from the graves, up to a maximum distance of 14 m (Figure 11).

3.2.3 Collection of soil solution

Within a 12 hour window of a rain event a vacuum of 1 bar was applied to each lysimeter and then left to collect soil solution for 24 hours. No additional water in the form of irrigation was added at this study site, so all nutrient transport was dependent on rain events. After collection of soil solution, samples were transported to the NaWA laboratory for analysis. Not all lysimeters produced solution and often the volume of solution was too small to be used. Due to the lack of rain events and unreliability of the lysimeters in solution collection, this part of the project was abandoned in June 2014 with only 84 samples collected.

3.2.4 Collection of soil cores for water extracts

The lack of significant rain events providing soil solution in the lysimeters between March and May 2014 facilitated the decision to take soil cores down slope of the graves was made. Soil cores were taken periodically between May 2014 and February 2015

3.2.4.1 Soil sampling and processing

Single soil cores were taken with a 2 cm diameter soil probe within 15 cm of the installed lysimeter to a depth corresponding to the installed lysimeter (i.e. 15 cm depth lysimeters had soil cores taken at 15 cm depth). Soil cores were transferred to labelled Ziploc bags and transported to the NaWA laboratory where the bags were opened so that

the soil was exposed to the air for drying for a 1-2 week period. Soils were sieved to 2 mm after air drying.

3.2.4.2 Water extractions of soil samples

Soil (3.5 g) was weighed into 50 mL HDPE centrifuge tubes and 35 g of ultra-pure water was added to achieve a 1:10 soil:water ratio. The centrifuge tubes with soil and water were shaken (on a rotary shaker) for 20 hours at 500 rpm. Samples were then centrifuged for 15 minutes at 19,974 g-force. pH and EC were quantified on unfiltered samples. Samples were then filtered to remove any floating organic matter with a Whatman GF/F filter (nominal pore size of 0.7 µm). Water extractable nutrients were analyzed immediately after extraction or frozen for later analysis.

3.2.5 Chemical analyses

Dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) were measured using high-temperature Pt-catalyzed combustion with a Shimadzu TOC-VCSH and Shimadzu total measuring unit TNM-1 (Shimadzu Corp. Houston, TX, USA). Dissolved organic carbon was measured as non-purgeable carbon using USEPA method 415.1, which entails acidifying the sample and sparging for 4 minutes with C-free air. Ammonium-N was analyzed using the phenate hypochlorite method with sodium nitroprusside enhancement (USEPA method 350.1) and nitrate-N was analyzed using Cd-Cu reduction (USEPA method 353.3). Orthophosphate-P concentrations were quantified using the ascorbic acid, molybdate-blue method (USEPA method 365.1). All

colorimetric methods were performed with a Smartchem Discrete Analyzer (Westco Scientific Instruments Inc. Brookfield, CT, USA). Dissolved organic nitrogen (DON) was calculated as the difference of TDN − (NH_4-N + NO_3-N). Check standards and NIST traceable standards were run every 12th sample to test for instrument precision and accuracy.

3.2.6 Statistical analyses

Average and standard deviations were computed for each nutrient by distance from grave and sample depth. Two sample, 1-tailed tests, assuming equal variance were performed for each individual nutrient for each distance from grave based on the hypothesis that soils downslope from pet graves would have significantly higher nutrient concentrations than soils downslope of control graves. This information was used with a time series of nutrient concentration for the control and pet graves for each distance and soil depth.

To determine whether the experimental pet graves had significantly higher nutrient concentrations downslope of their graves over the whole study period (349 days since burial) an analysis of variance was performed with type of grave (control or pet grave) as the independent variable and each nutrient in turn as the dependent variable (Control Graves: n = 152 and Pet Graves: n = 149). In order to assess any significant effects of distance from graves of depth of sample between the two grave classes a univariate analysis of variance was performed with distance from grave and soil depth as independent variables and nutrient as the dependent variable.

3.3 Results

3.3.1 Lysimeters

Soil solutions were collected for the first 215 days post burial. Through the course of the study, 84 lysimeter samples were analyzed between March and June 2014. Although more samples were collected, the volume was too small to analyze or the lysimeters did not consistently produce a sample.

Pooling all solutions for each site independent upon depth of sample or distance from grave only soil solution NO_3-N was significantly higher in the pet grave soils compared to the control grave soils (Table 23).

Table 23. Average soil solution nutrient concentrations for the two grave types. Differences in superscript lower case letters indicate a significant difference at $\alpha < 0.01$.

	pH	EC	NO_3-N	NH_4-N	PO_4-P	DOC	DON
		$\mu S\ cm^{-1}$	$mg\ L^{-1}$				
Graves	7.3	661	0.29^a	0.75	0.64	77.2	5.9
Controls	7.4	615	0.15^b	0.73	0.51	79.4	2.1

No effect of type of grave was observed in soil solution nutrients (Table 24). There was a significant effect of distance from the graves on soil solution EC and PO_4-P concentration (Table 24). A significant interaction effect of distance from grave and type of grave was observed for PO_4-P (Table 24).

Table 24. Significance (*p value*) of grave type, distance from grave and type of grave and distance from grave interactions on nutrients in soil solution. Significant effects are bold.

	pH	EC	NO_3-N	NH_4-N	PO_4-P	DOC	DON
Type of Grave	0.15	0.16	0.33	0.91	0.67	0.64	0.52
Distance from Grave	0.5	**0.01**	0.53	0.33	**0.001**	0.88	0.48
Type x Distance Interaction	0.22	0.11	0.63	1.00	**0.001**	0.79	0.65

Soil solution PO_4-P concentrations were significantly higher 14 m downslope from the control grave sites when compared to soil solution PO_4-P concentrations between 1 and 9 m downslope of the control grave sites ($p < 0.05$). Analysis of variance (ANOVA) revealed no significant effect of distance for the experimental grave site for pH, EC or any of the nutrients analyzed in the soil solution. There were no significant differences between the experimental and control grave sites for any of the chemical constituents analyzed (Student 2-sample, 2-tail T-Test; $p > 0.05$).

3.3.2 Water extractable nutrients

Over the course of the experiment, 349 d since the burial of pets or construction of control graves some significant differences in water extractable soil nutrients were found. There was no significant difference between the two grave sites for water extractable NO_3-N concentrations ($p = 0.07$), NH_4-N ($p = 0.10$) or DON ($p = 0.30$) (Table 25). Water extractable PO_4-P concentration was significantly higher for pet

graves compared to control graves ($p = 0.02$) and DOC concentration was significantly higher for pet graves compared to control graves ($p = 0.01$) (Table 25).

Table 25. Concentrations of water extractable nutrients from the control and experimental grave sites. Differences in superscript lower case letters indicate a significant difference at $\alpha < 0.05$.

	NO_3-N	NH_4-N	PO_4-P	DOC	DON
			μg g soil^{-1}		
Control	8.8	4.2	4.8[a]	199[a]	15.0
Grave	10.0	5.0	5.8[b]	233[b]	18.4

Table 26. Significance (*p value*) of grave type, depth of sample, distance from grave and their interactions on nutrients in soil solution. Significant effects are bold.

	NO_3-N	NH_4-N	PO_4-P	DOC	DON
Type of Grave	0.25	0.42	0.13	**0.01**	0.33
Distance from Grave	**0.003**	0.40	**<0.001**	0.07	0.29
Depth of sample	**<0.001**	0.55	**<0.001**	**0.04**	0.14
Type x Distance Interaction	0.88	0.84	**0.001**	0.33	0.06
Type x Depth Interaction	0.32	0.13	0.53	0.08	0.20
Distance and Depth Interaction	0.23	0.86	0.76	0.81	0.35
Type x Distance x Depth Interaction	0.89	0.36	0.82	0.30	0.19

Univariate analysis of variance found no significant effect of type of grave on water extractable NO_3-N, but a significant effect of distance from grave ($p = 0.003$) and depth of sample ($p < 0.0001$). There were no significant interactions of type of grave,

distance from grave or depth of sample on water extractable NO_3-N concentrations (Table 26).

There was no significant effect of type of grave, distance from grave or depth of soil sample on water extractable NH_4-N concentrations ($p = 0.40 – 0.55$) or interactions among the independent variables ($p = 0.13$-0.86; Table 26). Water extractable PO_4-P concentrations were significantly affected by distance from grave ($p < 0.001$), depth of soil sample ($p < 0.001$) and the interaction between grave type and distance from the grave ($p = 0.001$; Table 26). Water extractable DOC was significantly affected by the type of grave ($p = 0.01$) and the depth of the sample ($p = 0.04$) but distance from grave was not significant ($p = 0.07$) and neither was the interaction between type of grave and depth of sample ($p = 0.08$; Table 26). No effect of grave, depth of sample or distance from grave was observed for water extractable DON although the interaction of type of grave and distance from grave may prove to be significant with further time ($p = 0.06$).

3.3.3 Nutrient concentrations time series

Examination of a time series ranging from 117 to 349 d post burial (DPB) for all nutrients by distance from grave and depth of sample gave an indication of how nutrients differed between the two sites over time (Figures 12 to 19).

3.3.3.1 Nutrient concentrations within grave sites at 0-15 cm depth

Nitrate-N concentrations peaked 147 d after burial at 0-15 cm within the pet grave sites and were significantly higher than concentrations observed in the control graves (Figure 12A). While there was no significance difference between control and

pet graves for ammonium-N concentrations, concentrations peaked in pet grave soil at 184 d post burial where they were higher compared to control graves but not significantly higher (Figure 12B). Dissolved organic nitrogen concentrations were much lower than those observed for inorganic-N and were statistically similar when comparing control and pet graves for the course of the study except for 349 d post burial where concentrations of DON in the pet grave soil was significantly higher than the control soil ($p = 0.04$; Figure 12C). DOC concentrations were higher after 184 d post burial in the pet grave soil when compared to the control grave soil, but not significantly higher (Figure 12D). Although PO_4-P showed higher concentrations in pet grave soil compared to control soil at 0-15 cm at 290 and 349 d post burial, concentrations were not significantly higher (Figure 12E).

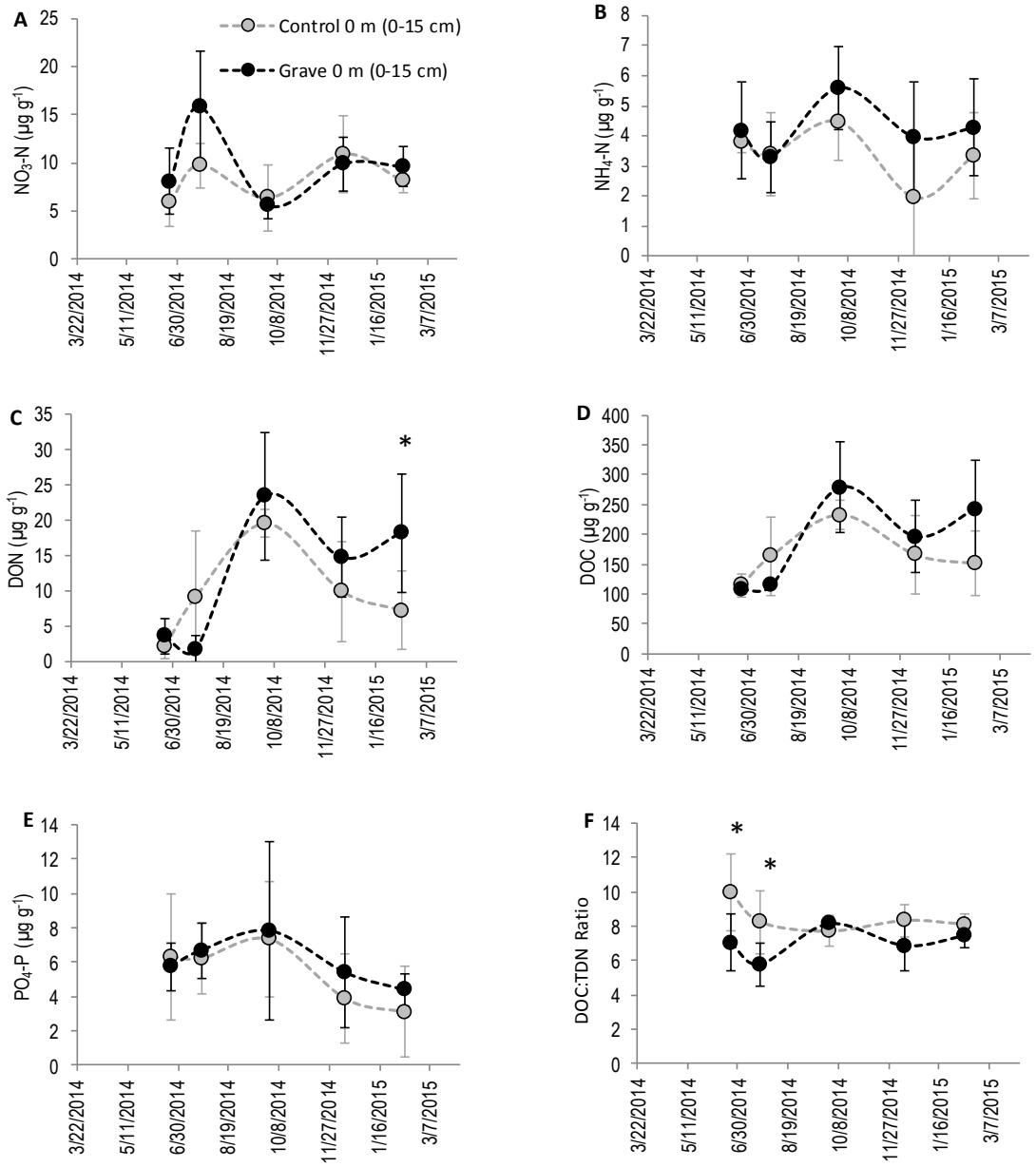

Figure 12. Time series of nutrient concentrations 0 m from grave and at depth of 0-15 cm. Time series of nutrient concentrations of water extracts from soil collected 0 meters from the control graves (grey circles) and pet graves (black circles). At a depth of 0-15

cm. Error bars are standard deviation. * significant difference ($p < 0.05$) based on a two sample, 1 tailed T-Test assuming similar variance.

3.3.3.2 Nutrient concentrations within grave sites at 15-30 cm depth

At 15-30 cm depth within the grave sites, it would be expected that significant difference in soil nutrients would be apparent over time since the graves themselves were at a depth of 60 cm. Nitrate-N concentrations were significantly higher in the control grave soils at 117 d after disturbance (Figure 13A), but thereafter were not significantly different when comparing the two grave types. Ammonium-N concentrations peaked in the pet grave soils at 15-30 cm depth 349 d after burial when they were significantly higher than control grave soil ammonium-N concentrations (Figure 13B). DON concentrations peaked in pet grave soil at 15-30 cm depth at 184 d post burial, but concentrations of DON were not significantly different when comparing pet and control graves (Figure 13C). Dissolved organic carbon concentrations were significantly higher in pet grave soils at 184 and 349 d after burial at the 15-30 cm depth when compared to control grave soils (Figure 13D). Orthophosphate-P concentrations in pet grave soils did not display any difference to control grave soils until 290 and 349 d post burial, but only PO_4-P concentrations at 349 d after burial were significantly higher (Figure 13E).

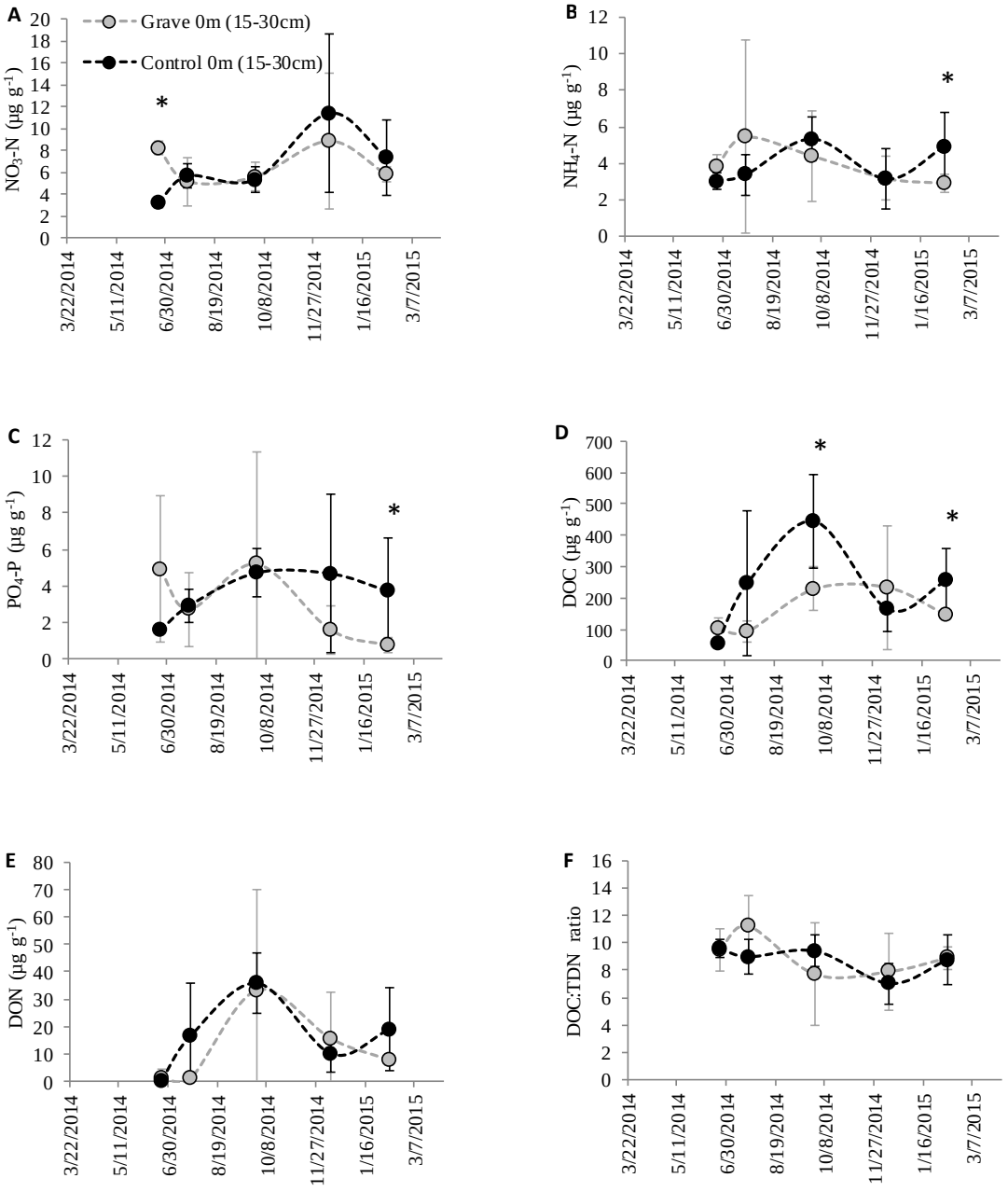

Figure 13. Time series of nutrient concentrations 0 m from grave and at depth of 15-30 cm. Time series of nutrient concentrations of water extracts from soil collected 0 meters from the control graves (grey circles) and pet graves (black circles) and at depth 15-30

cm. Error bars are standard deviation. * significant difference ($p < 0.05$) based on a two sample, 1 tailed T-Test assuming similar variance.

3.3.3.3 Nutrient concentrations 1 m from grave sites at 0-15 cm depth

At 1 m downslope of the grave sites at a depth of 0-15 cm, NO_3-N concentrations showed bimodal peaks with the first peak occurring 147 d after burial and the second peak 290d after burial. This was mirrored in the control graves. 290 d after burial, NO_3-N concentrations in the pet grave were higher than control graves, but not significantly so (Figure 14A). Ammonium-N concentrations peaked at 147 d post burial at the pet graves and were significantly higher 184 d post burial for pet graves compared to control graves. Pet grave NH_4-N concentrations were significantly lower when compared to control graves at 290 d after burial (Figure 14B). Orthophosphate-P concentrations in the pet graves were higher than the control graves at 147 and 184 d after burial, but not significantly higher (Figure 14C). DOC concentrations in the pet grave soil were higher than observed for control grave DOC concentrations for a majority of the study period starting at 147 d post burial (Figure 14D). DON concentrations in the pet grave soil peaked at 184 d after burial, but overall there was no significant difference in DON concentrations between the pet graves and control graves (Figure 14E). The DOC:TDN ratio showed no significant difference when comparing pet graves and control graves (Figure 14F).

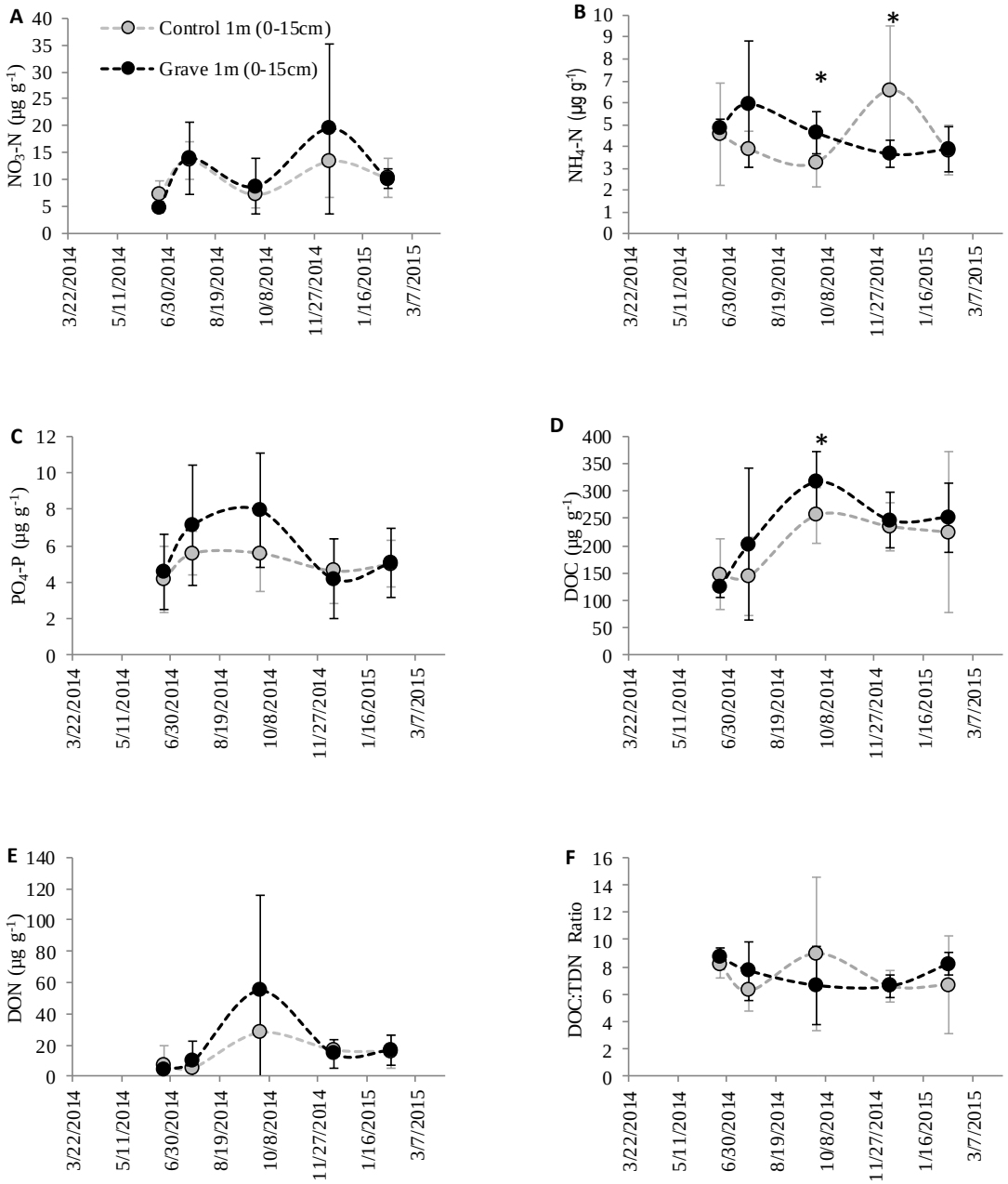

Figure 14. Time series of nutrient concentrations 1 m from grave and at depth of 0-15 cm. Time series of nutrient concentrations of water extracts from soil collected 1 meter from the control graves (grey circles) and pet graves (black circles). Error bars are

standard deviation. * significant difference ($p < 0.05$) based on a two sample, 1 tailed T-Test assuming similar variance.

3.3.3.4 Nutrient concentrations 1 m from grave sites at 15-30 cm depth

At the 15-30 depth and 1 m from the grave sites, NO_3-N was not significantly different when comparing the pet graves and control graves during the course of the study. At 290 d after burial, pet grave NO_3-N concentrations dropped below those of the control graves, but this was not significant (Figure 15A). Ammonium-N showed a peak in concentrations at the control sites 290 d after disturbance and a peak in NH_4-N concentrations at 349 d post burial in the pet graves although overall there were no significant differences in NH_4-N concentrations between the pet and control graves (Figure 15B). PO_4-P concentrations in the pet graves peaked at 184 d post burial and again at 349 d post burial although PO_4-P concentrations were only significantly higher in the pet graves at 184 d post burial (Figure 15C). DOC concentrations 1m from the grave sites at 15-30 cm depth in the control grave sites displayed an expected seasonality, low concentrations at the start and finish of the study and peaking in September 2014 (Figure 15D). In the pet graves, DOC displayed a steady increase with no seasonality and peaked at 349 d post burial (Figure 15D). There were no significant differences in DOC concentrations when comparing control and pet graves (Figure 15D). DON concentrations for the control graves displayed a similar seasonality as DOC concentrations and DON concentrations in pet graves displayed a similar steady rise peaking at 349 d post burial when DON concentrations were significantly higher in the pet graves when compared to the control graves ($p < 0.05$; Figure 15E).

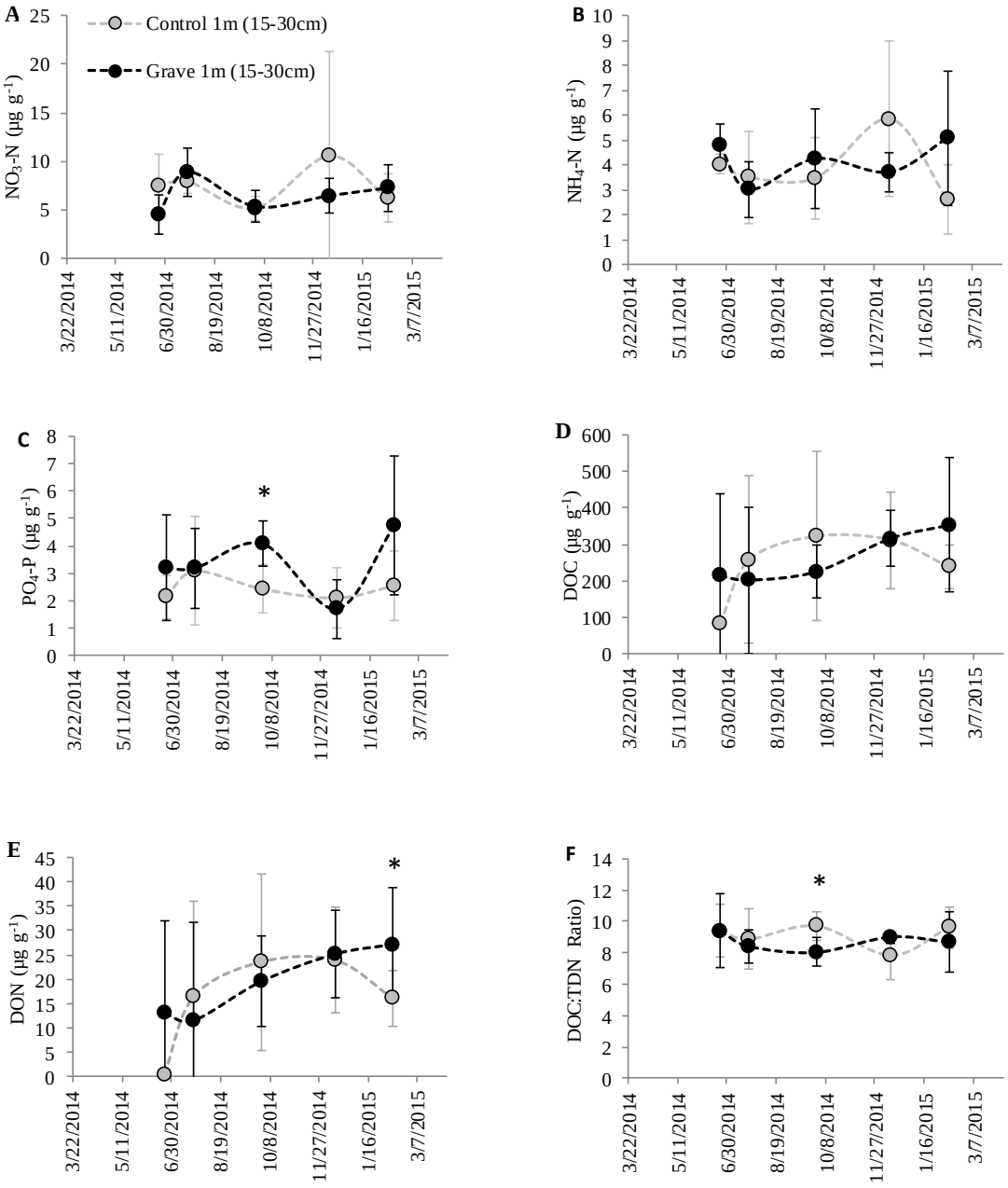

Figure 15. Time series of nutrient concentrations 1 m from grave and at depth 15-30 cm. Time series of water extracts from soil collected 1 meters from the control graves (grey circles) and pet graves (black circles) and at depth 15-30 cm. Error bars are standard

deviation. * significant difference ($p < 0.05$) based on a two sample, 1 tailed T-Test assuming similar variance.

The DOC:TDN ratio was very similar throughout the course of the study when comparing pet and control graves, but the control graves had significantly higher DOC:TDN ratio at 184 d post burial ($p = 0.02$; Figure 15F).

3.3.3.5 Nutrient concentrations 3 m from grave sites at 0-15 cm depth

At a 3 m distance from the grave sites and at a depth of 0-15 cm, NO_3-N and NH_4-N concentrations at the pet graves were very similar to concentrations at the control graves throughout the course of the study (Figures 16A and 16B). The only peaks observed for NO_3-N and NH_4-N concentrations in pet graves were at 117 d post burial when concentrations were higher than control graves but not significantly higher (Figures 16A and 16B). In contrast, DON concentrations were higher for the pet grave sites than control graves at 147 and 184 d post burial and significantly higher at 184 d post burial ($p = 0.02$). DOC concentrations peaked at 184 d post burial at the pet grave sites resembling a similar peak and timing as the control grave sites but there were no significant differences in DOC concentrations between the pet and control graves (Figure 16E). Orthophosphate-P concentrations peaked at the pet grave sites at 184 d post burial where they were significantly higher when compared to the control grave sites ($p = 0.02$; Figure 16C). There was no significant difference in the DOC:TDN ratio when comparing pet and control graves (Figure 16F).

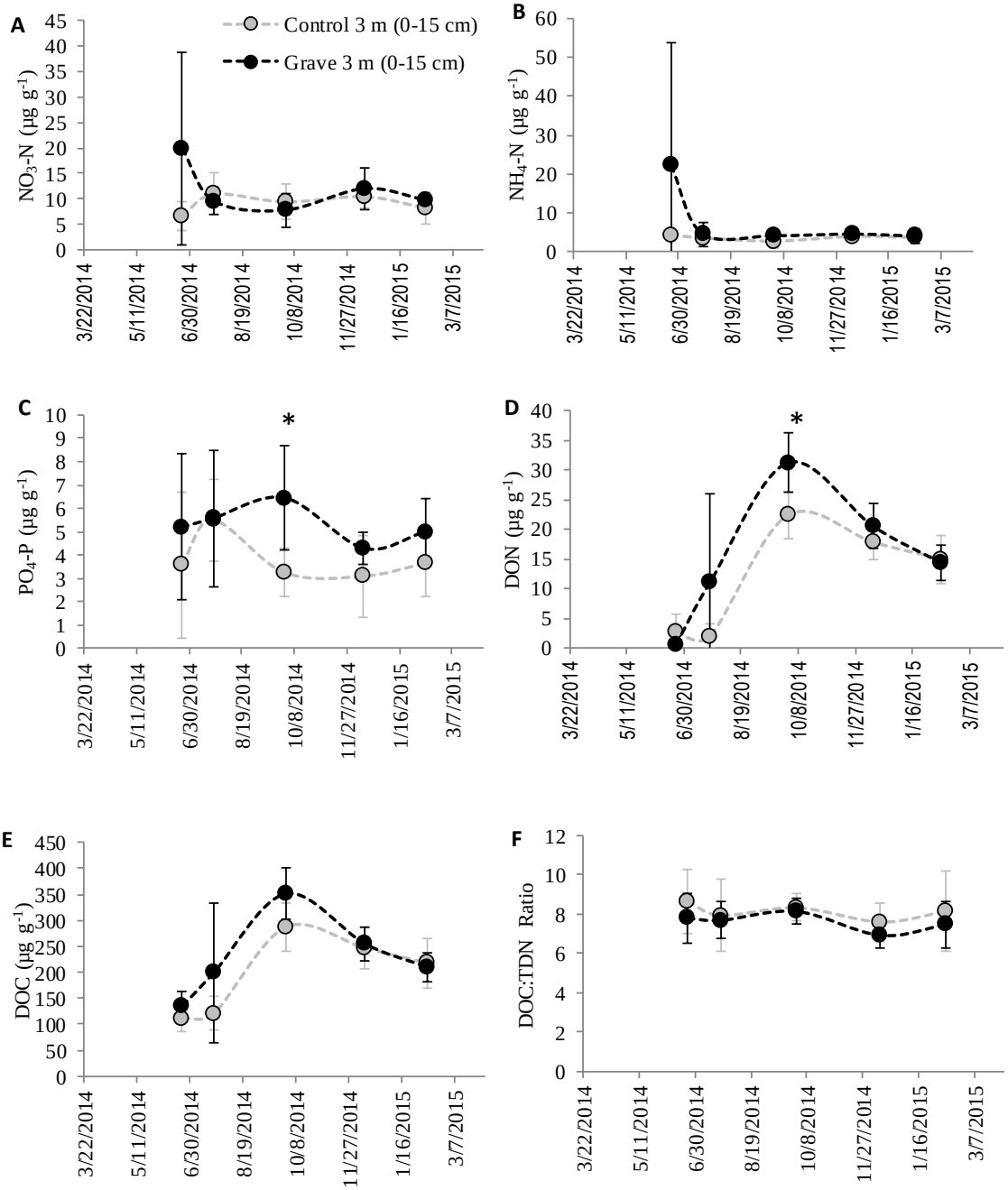

Figure 16. Time series of nutrient concentrations 3 m from gave and at depth of 0-15 cm. Time series of water extracts from soil collected 3 meters from the control graves (grey circles) and pet graves (black circles). Error bars are standard deviation. * significant difference ($p < 0.05$) based on a two sample, 1 tailed T-Test assuming similar variance

3.3.3.6 Nutrient concentrations 3 m from grave sites at 15-30 cm depth

Three meters from the grave sites at a depth of 15-30 cm most nutrients showed higher concentrations in pet grave soils when compared to control grave soils (Figure 17). NO_3-N concentrations were higher in the pet grave soils when compared to the control grave soils for the course of the study, but only significantly higher at 290 d post burial (Figure 17A). In contrast, NH_4-N concentrations for the pet grave sites were similar to control grave sites throughout the course of the study except at 147 d when control grave NH_4-N peaked (Figure 17B). Orthophosphate-P concentrations were higher in the pet grave soils when compared to the control grave soils throughout the course of the study at 3 m downslope of grave sites and 15-30 cm depth (Figure 17C). DOC concentrations at 3 m downslope of the graves and 15-30 cm depth were relatively constant over the course of the study for both the pet graves (280-365 µg g soil^{-1}) and control graves (151-182 µg g soil^{-1}) and pet grave DOC concentrations were higher than control grave DOC concentrations throughout the course of the study (Figure 17D). In contrast, DON concentrations in pet graves peak at 184 d post burial with significantly higher DON concentrations at 290 d post burial in pet grave soils when compared to control grave soils ($p = 0.03$; Figure 17E). DOC:TDN ratio was mostly consistent for control grave sites, but a significant drop in DOC:TDN ratio was observed at 184 d post burial for the pet grave sites (Figure 17F).

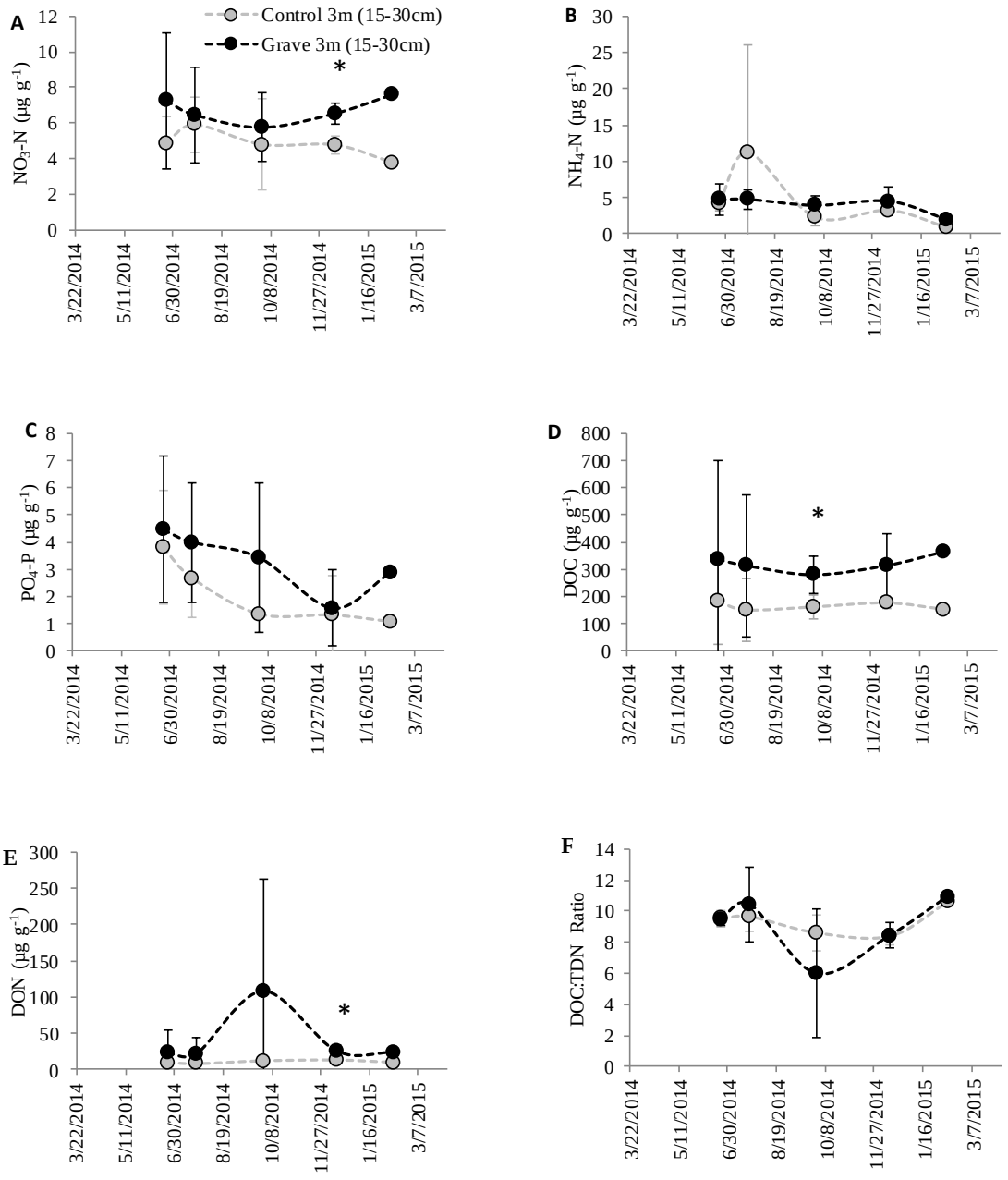

Figure 17. Time series of nutrient concentrations 3 m from grave and at depth of 15-30 cm. Time series of water extracts from soil collected 3 meters from the control graves (grey circles) and pet graves (black circles) and at depth 15-30 cm. Error bars are

standard deviation. * significant difference ($p < 0.05$) based on a two sample, 1 tailed T-Test assuming similar variance.

3.3.3.7 Nutrient concentrations 7 m from grave sites at 0-15 cm depth

At this distance, samples were only taken 0-15 cm from surface, but there were still significant differences seen between control graves and pet graves. Nitrate-N was fairly constant for the study sites with a slight increase when comparing day 117 to 349 post burial (Figure 18A). In the control graves nitrate-N concentrations exhibited a bi-modal peak at days 147 and 290 however these peaks were not statistically significantly different from the pet graves (Figure 18A). Ammonia-N concentration was significantly higher at 184 d post burial for the pet graves (Figure 18B). Orthophosphate-P concentrations were significantly higher for the pet graves at day 117 when compared to control graves (Figure 18C). During the course of the study, grave concentrations of orthophosphate-P decreased to closely match the control grave concentrations. DOC and DON concentrations closely mirrored each other as far as the shape of time series at this distance from the pet grave sites (Figure 18C). The major difference being that the control graves peaked 184 d post burial, but was higher than for pet grave sites at 290 d post burial for DOC, while control values peaked and were higher 220d post burial for DON (Figure 18D and 18E). However, there were no significant differences in either DOC or DON concentrations. DOC:TDN ratio was very similar for throughout the course of the study with no significant differences (Figure 18F).

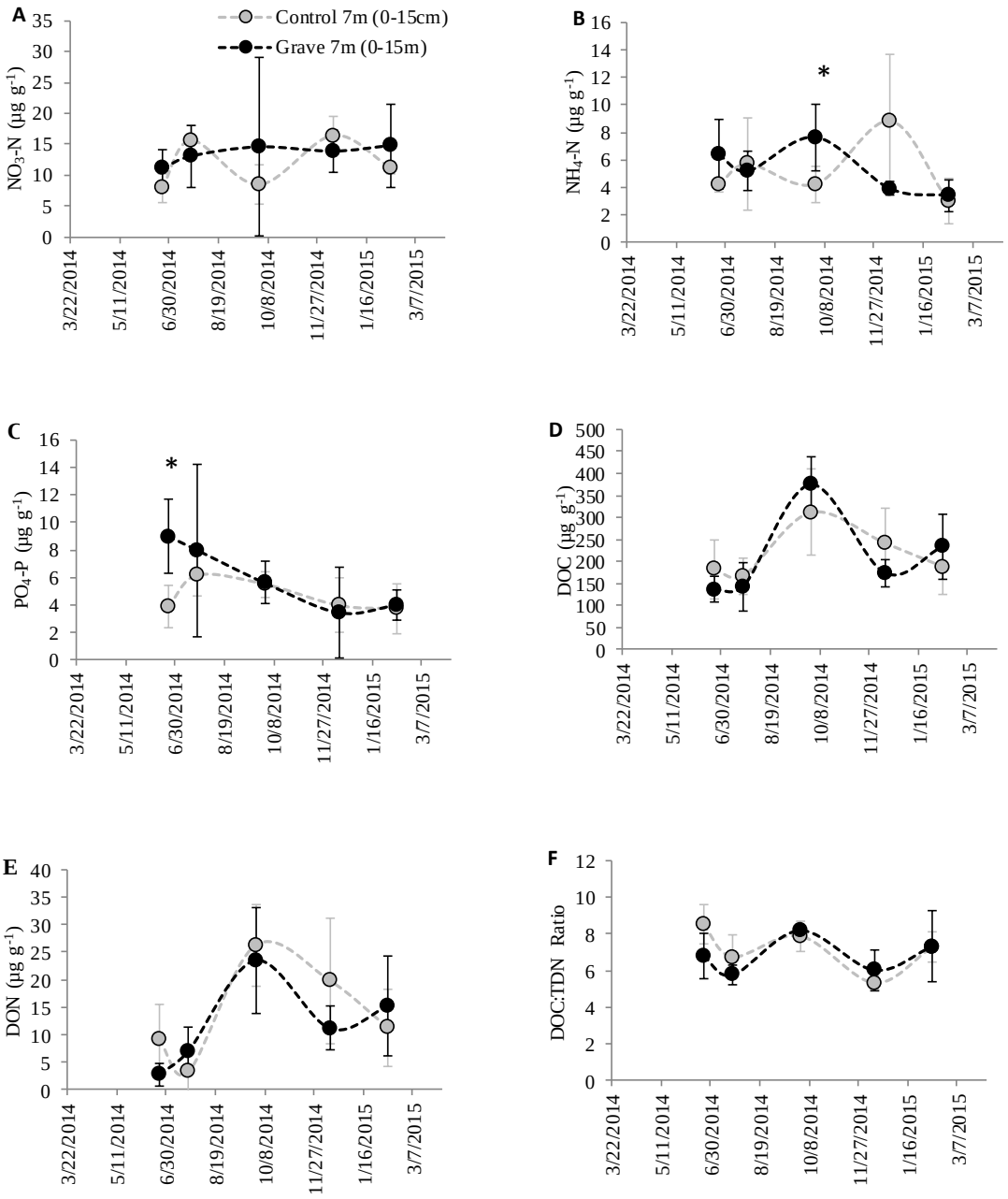

Figure 18. Time series of nutrient concentrations 7 m from grave and at depth of 0-15 cm. The control graves are grey circles, and pet graves are black circles. Error bars are standard deviation. * significant difference ($p < 0.05$) based on a two sample, 1 tailed T-Test assuming similar variance.

3.3.3.8 Nutrient concentrations 14 m from grave sites at 0-15 cm depth

While nitrate-N concentrations for the pet graves were higher than for controls control graves at 117 d post burial, by 184 d the post burial, controls control graves had higher NO_3-N concentrations, although not significantly so. For the remainder of the study, control and experimental groups had very similar means (Figure 19A). Ammonia-N also experienced a peak for pet grave sites, this time at 147 d post burial, but after this point control grave concentrations were higher for the remainder of the study (Figure 19B). Control graves ammonia-N concentrations were significantly higher than pet grave concentrations at 349 d post burial (Figure 19B). Additionally, pet grave concentrations for orthophosphate-P were significantly higher than control graves at 117 d post burial. Similarly, (Figure 19C) and control grave PO_4-P concentrations were higher for the remainder of the study with 184 and 349 days significantly so (Figure 19C). This site also marked a difference between DOC and DON (Figure 19D and 19E). While the pet grave DOC concentrations closely followed the time series shape of the control graves, in the control graves higher DOC concentrations were observed for the majority of the study. DON concentrations in the pet graves were almost indistinguishable from the control graves for all sampling dates except 184 d post burial where a peak in control grave DON concentration was observed (Figure 19D and 19E). DOC:TDN ratios in the pet graves were higher at 184 d post burial, but control groups experienced higher values both at 117 d post burial and but not significantly higher. The control graves had a significantly higher DOC:TDN ratio at 349 d post burial (Figure 19F).

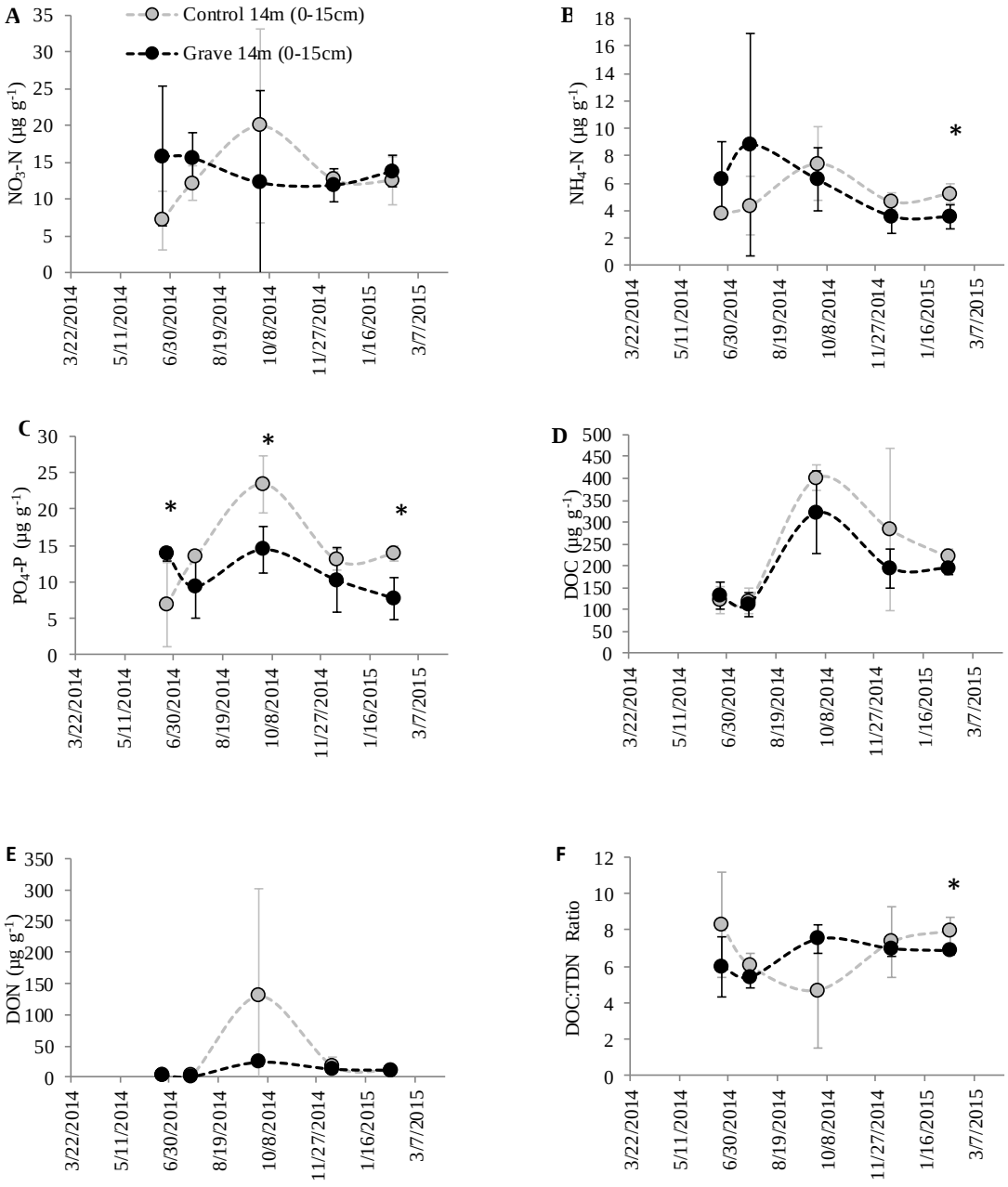

Figure 19. Time series of nutrient concentrations 14 m from grave and at depth of 0-15 cm. Time series of water extracts from soil collected 14 meters from the control graves (grey circles) and pet graves (black circles). Error bars are standard deviation. *

significant difference ($p < 0.05$) based on a two sample, 1 tailed T-Test assuming similar variance

3.3.4 Nutrient concentrations changes downslope of grave sites

The major objective for this study was to determine whether nutrient concentrations downslope of pet graves were increasing relative to control graves at points in time post burial. At 117 days post burial (DPB), NO_3-N concentrations were relatively consistent between 1 and 14 m downslope of the control graves, but for the pet grave sites NO_3-N concentrations were depressed at 1 m downslope of the graves and displayed an order of magnitude increase in concentration at 3 m downslope of the grave (Figure 20). Overall, at 117 DPB NO_3-N concentrations downslope of pet graves were higher relative to concentrations downslope of control graves (Figure 20). At 349 DPB NO_3-N concentrations were higher downslope of the pet graves compared to NO_3-N concentrations downslope of the control graves between 3 and 14 m downslope (Figure 20). Downslope concentrations of NH_4-N were consistent for the control graves, but displayed a large peak at 3m from the pet graves at 117 DPB (Figure 19). By 394 DPB, NH_4-N concentrations at sites downslope of both pet graves and control graves were similar and consistent (Figure 20). No distinct peaks of DOC concentration were observed down slope of pet graves (Figure 21). A small peak in DON concentration was observed at 184 DPB at 1m downslope of pet graves, but otherwise DON concentrations downslope of the grave sites were similar downslope for pet graves and control graves (Figure 21).

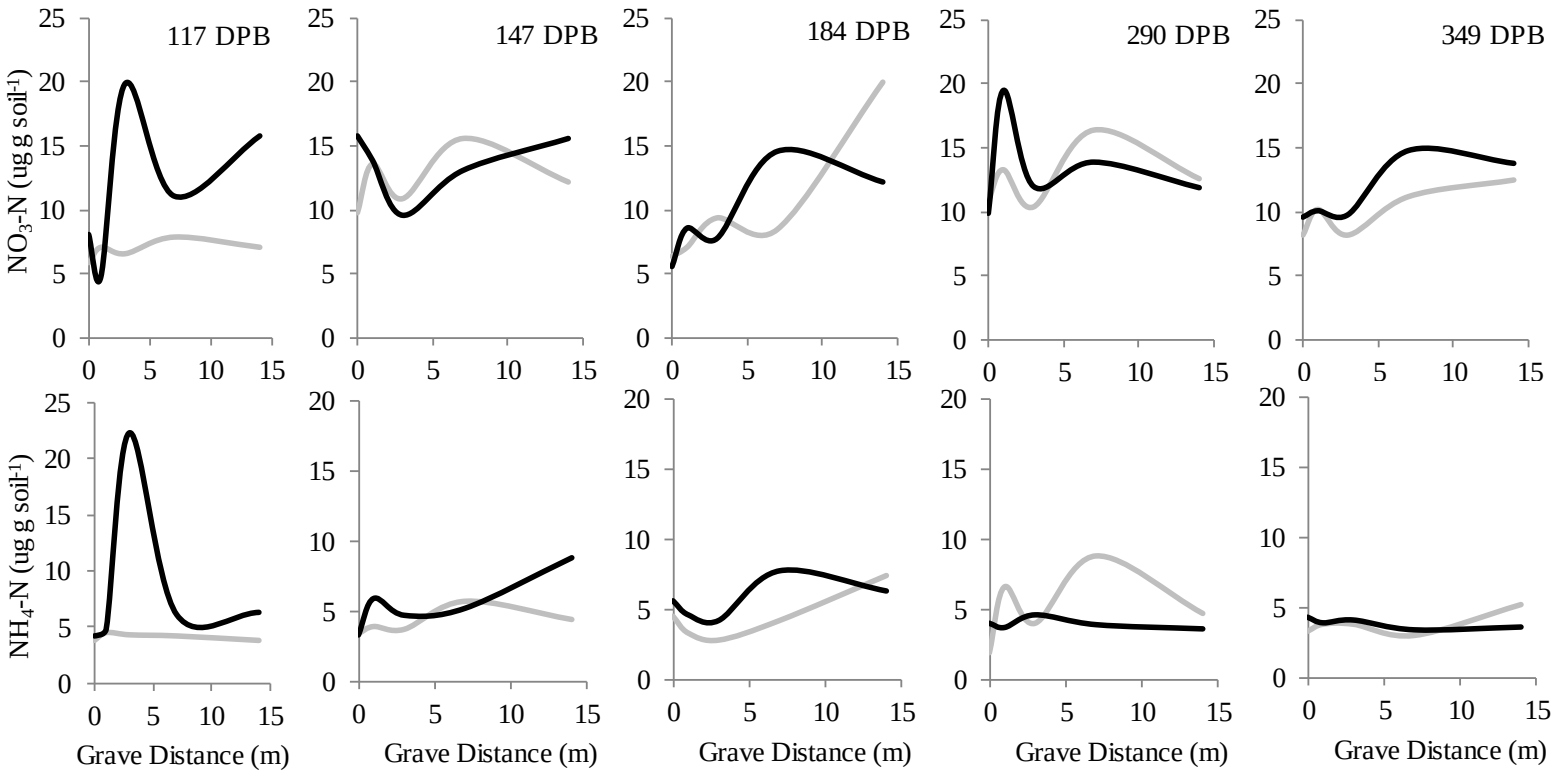

Figure 20. NO_3-N and NH_4-N concentrations with distance. Downslope from pet graves are represented with black lines and downslope from control graves are represented with grey lines.

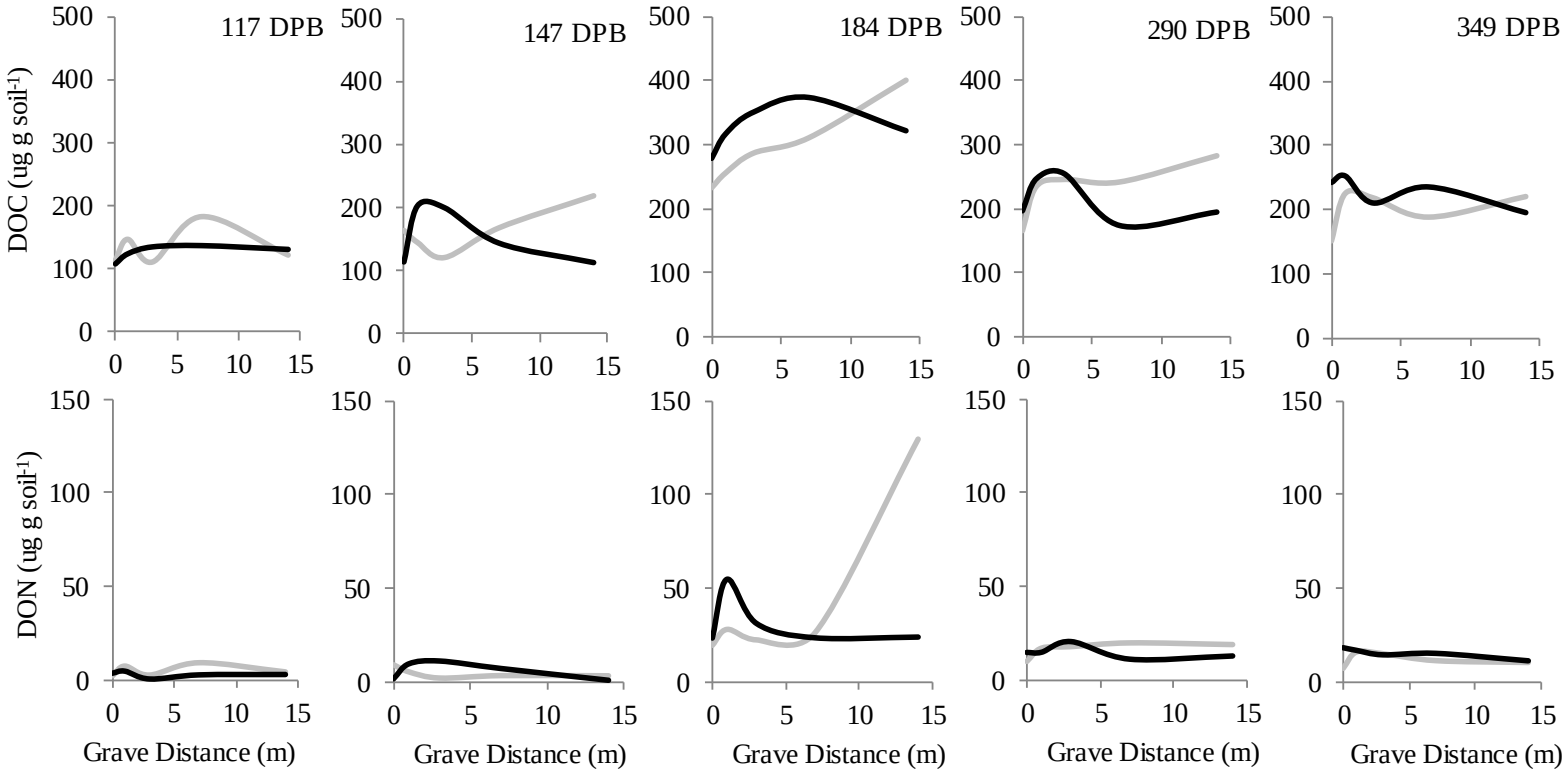

Figure 21. DOC and DON concentrations with distance. Downslope from pet graves are represented with black lines and control graves are represented with grey lines.

3.4 Discussion

Nitrogen species from a decomposing cadaver are generally in the form of ammonium-N and DON because the purge fluids comprise proteins, amino acids and amines (Aitkenhead-Peterson et al. 2012, 2015). When a cadaver decomposes on the surface of the soil the CDI is initially anaerobic due to the release of purge fluids and can remain anaerobic for almost a year (Aitkenhead-Peterson et al. 2012, 2015). This reducing soil environment induces soil microorganisms to utilize the oxygen in NO_3^- and SO_4^{2-} molecules (Aitkenhead-Peterson et al. 2012, 2015) generally resulting in low NO_3-N concentrations. In this study, NO_3-N concentrations were higher in the control grave soils when compared to the pet grave soils up to 1 m away from the grave sites at 117 d after burial suggesting that reducing conditions were occurring in the pet grave soils. The anaerobic conditions will also have an effect on nitrification which is an aerobic process and generally concentrations of ammonium-N and DON are higher than observed for nitrate-N in the CDIs of surface decomposing cadavers (Aitkenhead-Peterson et al. 2012, 2015). In this study there was no evidence of higher ammonium-N concentrations compared to nitrate-N concentrations in the pet grave soils, except at 117 days post burial at 1 m from the grave sites when NO_3-N and NH_4-N concentrations were both around 20 µg g soil-^{1}. Any aeration of soil such as the digging and refilling of graves will introduce oxygen into the soil atmosphere and encourage a high rate of nitrification; in fact, it was for this reason that control graves were dug and refilled because of the expectation of high nitrification rates through soil disturbance. Aitkenhead-Peterson et al. (2012) reported nitrate-N concentrations of 49 and 64 ug g

soil^{-1} in the CDI's of surface decomposing humans at 288 and 248 d post mortem. While these NO_3-N concentrations are between 2X and 4X higher than those observed in the current study, the mass of the subjects was between 2X and 4X higher prior to decomposition. An unpublished study on a surface decomposing Golden Retriever dog of an equivalent weight to the cadavers used in this study found soil CDI NO_3-N concentrations of 3 to 149 ug g soil^{-1} over a period of 30 to 198 d post mortem (Aitkenhead-Peterson unpublished). Soil samples taken beneath a 50 kg domestic pig showed a peak in NO_3-N concentration of 711 µg g soil^{-1} at 100 post mortem (Heo Chong Chin unpublished), which is a similar timing to the peak in NO_3-N concentration observed in this study 1m downslope of the pet graves. It may be that in a buried environment, NO_3-N concentrations do not peak at the same magnitude as surface cadavers because of loss of N to denitrification or alternatively that buried animals take much longer to decompose when compared to surface decomposition. Nevertheless, concentrations of NO_3-N were and lower in the soils of buried pets compared to the soils of a CDI.

Ammonium-N concentrations in the CDI's of two decomposing humans were 13 µg g soil^{-1} at 248 d post mortem and 52 µg g soil^{-1} at 288 d post mortem (Aitkenhead-Peterson et al., 2012). Although these concentrations are higher than observed in this current study between 177 and 349 d post burial within the pet grave sites (range: 3.3-22.3 µg g soil^{-1}), the weight difference between the cadavers and thus contribution of NH_4-N must be accounted for. However, NH_4-N concentrations in soil retrieved from surface decomposing domestic pigs were 47,541 µg g soil^{-1} peaking at 21 d post mortem

(Heo Chong Chin unpublished) much higher than observed in this study suggesting that we may well have missed the high NH_4-N peak due to not sampling until 117 d post burial. However, high peaks of NO_3-N and NH_4-N concentration were observed of 45 µg g soil^{-1} at 480 d for NO_3-N and 750 µg g soil^{-1} at 90 d and 600 µg g soil^{-1} at 480 d for NH_4-N for surface decomposing humans (Aitkenhead-Peterson et al. 2015).

Benninger et al. (2008) utilized domestic pigs (*Sus scrofa*) for a surface decomposition experiment and reported extractable phosphorus concentrations peaking at 0.18 µg g soil^{-1} at 20 d after death. PO_4-P concentrations at pet grave sites in the current study ranged from 4.2 to 14.5 µg g soil^{-1} at a 0-15 cm depth and no distinct peaks were observed. A distinct peak of PO_4-P concentration (497 µg g soil^{-1}) was observed at 40 d post mortem beneath surface decomposing domestic pig cadavers (Heo Chong Chin unpublished). One reason for the similar PO_4-P concentrations in both control and pet grave soil in this study may be legacy P derived from past grazing of dairy animals at the experiment site.

Dissolved organic carbon concentrations in soil CDI's differ significantly among species of animal and whether the cadaver is a surface decomposition or buried decomposition (Aitkenhead-Peterson et al. 2012, 2015; McDonald et al. 2014). McDonald et al. (2014) examined the soil in a CDI beneath decomposing kangaroos and reported DOC concentrations of around 650 µg g soil^{-1} at 84 days post mortem. Aitkenhead-Peterson et al. (2012) reported DOC concentrations of 1487 to 1084 µg g soil^{-1} at 248 and 288 days post mortem in CDI's beneath two surface decomposing humans. Peaks of DOC concentration are generally observed between 176 and 196 d

post mortem for human cadavers at concentrations of over 6,000 µg g soil^{-1} (Aitkenhead-Peterson et al. 2015). In the current study a peak of DOC concentration (374 µg g soil^{-1}) was observed at 184 d post burial in soil 7 m downslope of the pet graves at a depth of 0-15 cm. It is almost impossible to compare concentrations of decomposition products of buried cadavers to those in CDI's. Peak concentrations of nutrients in the CDI are expected during certain time periods with most surface decomposing cadavers which are generally within a window of 30 days depending on what time of year the cadaver was placed on the soil surface to decompose. Time to purge is generally 3 d for a naked human placed during the summer months and 30 d for a naked human placed in the winter months. Time to purge for other animal species with fur as protection may be different. Lack of distinct peaks in decomposition product concentration in this study are confounding, but may be due to a number of reasons: a) cold temperatures during the spring of 2014 delayed decomposition of the buried cadavers, b) delay in extracting soil cores until 117 d post burial and peaks were missed, c) lack of precipitation for transport out of the gravesite downslope may delay peak concentrations or d) peaks have not occurred yet and may be much later with buried cadavers than observed with CDIs.

Transport of animal decomposition products downslope of both surface and buried cadavers has been observed in other studies (Aitkenhead-Peterson et al. 2012; Yuan et al. 2013). Yuan et al. (2013) examined the leaching of decomposition nutrients, hormones and pharmaceuticals from buried cattle carcasses over a period of approximately 560 d. Most of the contaminants were observed in leachate at 50 d after burial and concentrations peaked at 200 d post burial and were similar to baseline

concentrations after 400 d post burial. Substantial leachate production did not however occur until after 370 d post burial. This leachate was collected directly from the pits holding 5-7 cattle carcasses and was of course subject to water infiltration; the grave sites received 1400 mm of precipitation over the course of the study. Because their results were for leachate and measured as mg L^{-1}comparison of their results to the current study was impossible. It should be reiterated that the current study included transport through the soil to a distance of 14 m downslope of the pet grave sites in which mechanisms such as adsorption and desorption to soil minerals and uptake by soil microbial communities and plants would occur likely decreasing observed concentrations. Nevertheless, there was some evidence of transport downslope of pet decomposition products in this study particularly for PO_4-P in the early lysimeter samples and for NO_3-N and PO_4-P for the soil extracts. The grave sites will be sampled once more in May 2015 and August 2015 just in case peak concentrations in burial sites are delayed significantly relative to CDI sites.

3.5 Conclusions

There are many different variables that contribute to the specific decomposition environment and the rate of decomposition. Some of these can be controlled in experimental design; for example, the species and type of cadaver, but many of the variables are independent and not well understood as of yet. This lack of understanding may lead to variation (and therefore, non-statistically significant results) within similar testing environments, as well as seeing differences in the effect of decomposition

products on the surrounding environment. The study found some evidence of transport specifically for NO_3-N and PO_4-P from the graves sites. Continued research is required for better understanding of the complex relationships with decomposition products and their possible contributions to water quality.

4 CONCLUSIONS

Chapter 2 focused on creating a background base of knowledge for the watershed. This background was then used to determine relationships and attempt to identify potential sources for contaminants in the watershed. Through the course of the analysis, all alternative hypotheses were accepted. A large amount of data was collected, but more research would help answer several questions. Specific analysis of sources would help identify need for improvements in infrastructure to limit point sources or, community awareness and education to decrease non-point sources. In addition, while a relationship was found between nutrients and *E. coli* concentrations, more data collection or statistical analysis may lead to the identification of a stronger Relationship. This data can be applied to community outreach and used to provide guidance to watershed managers as far as the background water quality on a higher density scale than the typical quartile data that is collected.

Chapter 3 examined a very specific field of research and potential source for nutrients in water quality. Several factors cause differences in decomposition and affect the timing of nutrient release into the soil profile. Continued research will help add to the data set and ensure that the release peak has not been missed in this study. For the study the alternative hypothesis was accepted, although significant differences were only seen in water extractable soil NO_3-N and PO_4-P concentrations.

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APPENDIX I

SEASONAL NUTRIENT CONCENTRATIONS FOR CARTERS CREEK

Seasonal nutrient concentrations for routine monitoring sites

		Site Number			
		11782	11783	11785	21259
Season	Statistic	Conductivity (µS/cm)			
Spring 2013	Mean	357	1253	1023	980
	Std Dev	± 95	± 146	± 150	± 177
Summer 2013	Mean	720	1165	1020	1078
	Std Dev	± 584	± 192	± 213	± 206
Fall 2013	Mean	290	1057	850	793
	Std Dev	± 108	± 327	± 318	± 301
Winter 2013	Mean	457	863	987	997
	Std Dev	± 81	± 237	± 157	± 172
Sprin 2014	Mean	383	1323	1050	1117
	Std Dev	± 72	± 126	± 92	± 174
Summer 2014	Mean	510	1445	1055	945
	Std Dev	± 113	± 163	± 92	± 247
Fall 2014	Mean	373	1263	1090	1043
	Std Dev	± 15	± 284	± 252	± 225
Winter 2014	Mean	364	1190	993	971
	Std Dev	± 164	± 108	± 178	± 216

		Site Number			
		11782	11783	11785	21259
Season	Statistic	DON (mg/L)			
Spring 2013	Mean	0.91	2.29	1.26	1.14
	Std Dev	± 3.99	± 2.60	± 4.43	± 4.36
Fall 2013	Mean	0.73	0.31	0.61	0.35
	Std Dev	± 0.13	± 0.08	± 0.19	± 0.31
Winter 2013	Mean	0.48	0.55	0.85	1.06
	Std Dev	± 0.24	± 0.56	± 0.75	± 0.93
Sprin 2014	Mean	1.10	7.29	6.25	4.64
	Std Dev	± 0.74	± 9.78	± 8.17	± 7.30
Summer 2014	Mean	0.28	0.00	0.00	0.01
	Std Dev	± 0.40	± 0.00	± 0.00	± 0.01
Fall 2014	Mean	0.65	1.09	6.82	0.77
	Std Dev	± 0.14	± 0.63	± 9.86	± 0.59
Winter 2014	Mean	0.41	1.35	1.03	0.96
	Std Dev	± 0.13	± 0.72	± 0.30	± 0.69

		Site Number			
		11782	11783	11785	21259
Season	Statistic	DON:TDN Ratio			
Spring 2013	Mean	0.62	0.10	0.06	0.06
	Std Dev	± 0.08	± 0.11	± 0.05	± 0.06
Summer 2013	Mean	0.37	0.10	0.18	0.18
	Std Dev	± 0.04	± 0.08	± 0.16	± 0.18
Fall 2013	Mean	0.66	0.01	0.03	0.02
	Std Dev	± 0.08	± 0.00	± 0.01	± 0.02
Winter 2013	Mean	0.35	0.05	0.05	0.06
	Std Dev	± 0.22	± 0.04	± 0.05	± 0.05
Sprin 2014	Mean	0.66	0.35	0.35	0.32
	Std Dev	± 0.17	± 0.48	± 0.48	± 0.51
Summer 2014	Mean	0.30	0.00	0.00	0.00
	Std Dev	± 0.42	± 0.00	± 0.00	± 0.00
Fall 2014	Mean	0.46	0.05	0.36	0.05
	Std Dev	± 0.12	± 0.03	± 0.51	± 0.03
Winter 2014	Mean	0.44	0.07	0.07	0.07
	Std Dev	± 0.24	± 0.05	± 0.02	± 0.03

		Site Number			
		11782	11783	11785	21259
Season	Statistic	NH4-N mg/L			
Spring 2013	Mean	0.20	0.24	0.23	0.21
	Std Dev	± 0.01	± 0.03	± 0.02	± 0.02
Summer 2013	Mean	0.22	0.27	0.36	0.23
	Std Dev	± 0.01	± 0.08	± 0.25	± 0.04
Fall 2013	Mean	0.11	0.17	0.19	0.18
	Std Dev	± 0.03	± 0.01	± 0.06	± 0.02
Winter 2013	Mean	0.09	0.18	0.14	0.15
	Std Dev	± 0.01	± 0.03	± 0.04	± 0.05
Sprin 2014	Mean	0.17	0.52	0.23	0.17
	Std Dev	± 0.03	± 0.48	± 0.08	± 0.03
Summer 2014	Mean	0.13	0.20	0.19	0.19
	Std Dev	± 0.01	± 0.04	± 0.07	± 0.08
Fall 2014	Mean	0.13	0.26	0.21	0.27
	Std Dev	± 0.02	± 0.13	± 0.09	± 0.03
Winter 2014	Mean	0.15	0.17	0.22	0.19
	Std Dev	± 0.02	± 0.02	± 0.03	± 0.03

		Site Number			
		11782	11783	11785	21259
Season	Statistic	NO3-N mg/L			
Spring 2013	Mean	0.37	23.30	19.48	17.21
	Std Dev	± 0.21	± 6.10	± 2.08	± 1.34
Summer 2013	Mean	5.68	23.98	17.60	14.62
	Std Dev	± 7.05	± 2.35	± 2.72	± 1.44
Fall 2013	Mean	0.29	23.98	18.17	15.23
	Std Dev	± 0.14	± 4.37	± 2.47	± 1.65
Winter 2013	Mean	0.90	16.18	15.66	16.97
	Std Dev	± 0.52	± 9.21	± 2.64	± 0.10
Sprin 2014	Mean	0.30	13.15	12.50	11.37
	Std Dev	± 0.25	± 9.59	± 9.36	± 8.79
Summer 2014	Mean	1.15	22.31	14.82	10.89
	Std Dev	± 1.27	± 0.24	± 4.20	± 8.75
Fall 2014	Mean	0.65	18.52	10.90	14.38
	Std Dev	± 0.30	± 2.18	± 8.84	± 2.58
Winter 2014	Mean	0.45	17.78	13.43	11.86
	Std Dev	± 0.35	± 4.09	± 4.11	± 5.53

		Site Number			
		11782	11783	11785	21259
Season	Statistic	NPOC mg/L			
Spring 2013	Mean	37.41	50.31	45.40	44.14
	Std Dev	± 21.09	± 37.44	± 32.37	± 32.03
Summer 2013	Mean	16.47	11.82	10.57	11.58
	Std Dev	± 3.14	± 3.46	± 0.38	± 2.23
Fall 2013	Mean	22.58	20.02	21.90	20.84
	Std Dev	± 2.00	± 7.02	± 1.93	± 1.77
Winter 2013	Mean	20.00	22.74	21.76	22.76
	Std Dev	± 3.57	± 3.90	± 2.25	± 3.97
Sprin 2014	Mean	36.35	67.30	56.88	58.01
	Std Dev	± 14.55	± 35.52	± 27.82	± 28.81
Summer 2014	Mean	37.79	59.47	46.02	42.62
	Std Dev	± 20.72	± 38.04	± 14.52	± 8.07
Fall 2014	Mean	17.03	12.07	10.90	12.43
	Std Dev	± 1.14	± 3.57	± 3.48	± 0.77
Winter 2014	Mean	13.16	15.21	13.11	13.54
	Std Dev	± 2.95	± 3.16	± 1.00	± 1.33

		Site Number			
		11782	11783	11785	21259
Season	Statistic	pH			
Spring 2013	Mean	8.15	7.75	8.32	8.62
	Std Dev	± 0.31	± 0.05	± 0.10	± 0.29
Summer 2013	Mean	8.96	8.80	8.91	9.17
	Std Dev	± 0.45	± 0.52	± 0.19	± 0.14
Fall 2013	Mean	8.11	7.85	8.16	8.09
	Std Dev	± 0.67	± 0.86	± 0.83	± 0.79
Winter 2013	Mean	7.60	7.58	7.74	7.78
	Std Dev	± 0.40	± 0.32	± 0.27	± 0.14
Sprin 2014	Mean	7.17	7.43	7.95	8.08
	Std Dev	± 1.10	± 0.71	± 0.18	± 0.34
Summer 2014	Mean	7.26	7.18	7.37	7.61
	Std Dev	± 0.10	± 0.40	± 0.59	± 0.33
Fall 2014	Mean	7.94	7.82	8.11	8.14
	Std Dev	± 0.06	± 0.13	± 0.19	± 0.27
Winter 2014	Mean	7.72	7.83	8.15	8.06
	Std Dev	± 0.27	± 0.06	± 0.20	± 0.20

		Site Number			
		11782	11783	11785	21259
Season	Statistic	PO3-P mg/L			
Spring 2013	Mean	0.24	3.90	3.32	2.97
	Std Dev	± 0.03	± 0.64	± 0.41	± 0.38
Summer 2013	Mean	1.46	4.34	3.14	2.80
	Std Dev	± 1.57	± 0.03	± 0.17	± 0.24
Fall 2013	Mean	0.29	3.61	2.89	2.58
	Std Dev	± 0.08	± 0.65	± 0.54	± 0.56
Winter 2013	Mean	0.28	1.53	3.02	3.28
	Std Dev	± 0.10	± 1.45	± 0.19	± 0.27
Sprin 2014	Mean	0.34	4.07	3.60	2.98
	Std Dev	± 0.14	± 0.71	± 0.77	± 0.69
Summer 2014	Mean	0.44	4.07	2.76	2.11
	Std Dev	± 0.19	± 1.12	± 1.04	± 1.71
Fall 2014	Mean	0.51	3.25	2.09	2.66
	Std Dev	± 0.26	± 0.11	± 1.42	± 0.20
Winter 2014	Mean	0.81	2.11	1.73	1.60
	Std Dev	± 1.07	± 1.36	± 1.36	± 1.39

		Site Number			
		11782	11783	11785	21259
Season	Statistic	TN mg/L			
Spring 2013	Mean	1.49	17.37	19.63	16.67
	Std Dev	± 0.21	± 15.32	± 5.22	± 5.15
Summer 2013	Mean	9.28	27.34	22.56	18.96
	Std Dev	± 11.05	± 4.95	± 6.68	± 5.62
Fall 2013	Mean	1.13	24.47	18.97	15.76
	Std Dev	± 0.29	± 4.43	± 2.57	± 1.95
Winter 2013	Mean	1.47	16.44	16.50	17.93
	Std Dev	± 0.53	± 8.45	± 1.94	± 1.31
Sprin 2014	Mean	1.57	20.88	18.98	16.18
	Std Dev	± 0.70	± 2.17	± 2.12	± 2.14
Summer 2014	Mean	1.55	20.90	13.61	9.66
	Std Dev	± 0.85	± 1.29	± 2.57	± 6.65
Fall 2014	Mean	1.42	19.87	17.94	15.43
	Std Dev	± 0.28	± 2.65	± 1.68	± 2.89
Winter 2014	Mean	1.00	19.30	14.68	13.01
	Std Dev	± 0.27	± 3.94	± 4.29	± 6.10

		Site Number			
		11782	11783	11785	21259
Season	Statistic	DOC:DON Ratio mg/L			
Spring 2013	Mean	23.28	18.52	20.14	21.07
	Std Dev	± 23.28	± 18.52	± 20.14	± 21.07
Summer 2013	Mean	8.87	17.33	49.16	1.94
	Std Dev	± 8.87	± 17.33	± 49.16	± 1.94
Fall 2013	Mean	2.41	27.83	10.92	271.92
	Std Dev	± 2.41	± 27.83	± 10.92	± 271.92
Winter 2013	Mean	44.03	17.17	10.17	8.47
	Std Dev	± 44.03	± 17.17	± 10.17	± 8.47
Sprin 2014	Mean	16.27	3.87	301.38	130.33
	Std Dev	± 16.27	± 3.87	± 301.38	± 130.33
Summer 2014	Mean	66.40	0.00	0.00	3126.76
	Std Dev	± 66.40	± 0.00	± 0.00	± 3126.76
Fall 2014	Mean	3.99	12.55	6.47	13.60
	Std Dev	± 3.99	± 12.55	± 6.47	± 13.60
Winter 2014	Mean	4.20	9.35	3.54	12.56
	Std Dev	± 4.20	± 9.35	± 3.54	± 12.56

Seasonal nutrient concentrations for reconnaissance sites

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	Conductivity (µs/cm)									
Spring 2013	Mean	1220	323	627	860	873	1173	968	417	1103	553
	Standard Deviation	± 111	± 75	± 142	± 291	± 232	± 419	± 303	± 78	± 217	± 101
Summer 2013	Mean	1142	510	967	683	1452	1080	1650	532	1190	1012
	Standard Deviation	± 201	± 252	± 150	± 99	± 257	± 204	± 380	± 337	± 239	± 391
Fall 2013	Mean	1260	395	457	467	670	907	667	270	883	450
	Standard Deviation	± 252	± 267	± 197	± 117	± 357	± 309	± 492	± 119	± 390	± 255
Winter 2013	Mean	817	453	423	923	560	913	893	473	840	480
	Standard Deviation	± 301	± 83	± 46	± 76	± 127	± 142	± 180	± 120	± 161	± 82
Sprin 2014	Mean	1467	510	1077	967	1260	1145	1517	460	1167	760
	Standard Deviation	± 387	± 176	± 522	± 444	± 615	± 107	± 674	± 226	± 137	± 192
Summer 2014	Mean	1430	465	900	735	735	1088	1590	435	1070	742
	Standard Deviation	± 170	± 78	± 552	± 290	± 205	± 81	± 28	± 7	± 99	± 26
Fall 2014	Mean	1360	453	655	623	763	1160	940	470	1163	907
	Standard Deviation	± 368	± 123	± 106	± 150	± 67	± 270	± 372	± 42	± 224	± 139
Winter 2014	Mean	1043	341	496	724	601	1025	1033	362	991	721
	Standard Deviation	± 300	± 99	± 155	± 115	± 210	± 195	± 600	± 130	± 235	± 188

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	DON (mg/L)									
Spring 2013	Mean	3.23	0.69	0.77	0.83	2.31	1.61	1.20	0.67	0.95	0.88
	Standard Deviation	± 2.49	± 0.09	± 0.14	± 0.20	± 0.66	± 1.62	± 1.02	± 0.22	± 0.91	± 0.12
Summer 2013	Mean	1.22	0.81	1.42	0.89	3.63	3.86	0.87	1.74	3.30	1.66
	Standard Deviation	± 0.75	± 0.64	± 0.23	± 0.60	± 1.43	± 4.98	± 0.58	± 1.44	± 2.53	± 0.70
Fall 2013	Mean	0.73	0.61	0.72	0.71	1.22	1.10	0.65	0.90	0.53	1.37
	Standard Deviation	± 0.17	± 0.15	± 0.32	± 0.47	± 0.79	± 0.53	± 0.25	± 0.09	± 0.20	± 0.47
Winter 2013	Mean	0.57	0.39	0.46	0.37	0.50	0.54	0.27	0.75	0.41	0.74
	Standard Deviation	± 0.61	± 0.19	± 0.21	± 0.15	± 0.09	± 0.47	± 0.25	± 0.34	± 0.36	± 0.20
Sprin 2014	Mean	8.02	0.61	1.09	0.48	1.50	5.12	0.52	0.98	4.62	1.21
	Standard Deviation	± 10.57	± 0.18	± 0.36	± 0.10	± 0.99	± 6.19	± 0.21	± 0.12	± 7.26	± 0.09
Summer 2014	Mean	0.00	0.22	0.93	0.49	0.85	0.00	0.14	0.37	0.00	0.74
	Standard Deviation	± 0.00	± 0.31	± 0.26	± 0.03	± 0.56	± 0.00	± 0.19	± 0.03	± 0.00	± 0.84
Fall 2014	Mean	1.77	0.18	0.21	0.32	0.30	5.13	0.71	1.06	5.83	1.21
	Standard Deviation	± 0.91	± 0.17	± 0.11	± 0.30	± 0.31	± 6.72	± 0.66	± 0.56	± 8.22	± 0.69
Winter 2014	Mean	1.39	0.57	0.42	0.52	0.52	1.49	0.69	0.57	0.72	0.59
	Standard Deviation	± 0.38	± 0.14	± 0.04	± 0.16	± 0.37	± 0.54	± 0.26	± 0.17	± 0.47	± 0.26

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	DON/TDN									
Spring 2013	Mean	0.12	0.51	0.67	0.50	0.86	0.07	0.52	0.54	0.06	0.55
	Standard Deviation	± 0.11	± 0.07	± 0.07	± 0.08	± 0.04	± 0.07	± 0.14	± 0.26	± 0.05	± 0.14
Summer 2013	Mean	0.05	0.34	0.71	0.59	0.90	0.15	0.44	0.72	0.17	0.66
	Standard Deviation	± 0.03	± 0.22	± 0.17	± 0.25	± 0.05	± 0.18	± 0.24	± 0.25	± 0.12	± 0.27
Fall 2013	Mean	0.03	0.36	0.44	0.56	0.72	0.06	0.55	0.64	0.03	0.58
	Standard Deviation	± 0.01	± 0.33	± 0.25	± 0.10	± 0.20	± 0.02	± 0.16	± 0.11	± 0.01	± 0.11
Winter 2013	Mean	0.07	0.41	0.30	0.32	0.44	0.05	0.26	0.63	0.10	0.40
	Standard Deviation	± 0.08	± 0.08	± 0.20	± 0.13	± 0.28	± 0.05	± 0.28	± 0.06	± 0.14	± 0.08
Sprin 2014	Mean	0.36	0.39	0.76	0.52	0.67	0.35	0.45	0.79	0.31	0.79
	Standard Deviation	± 0.47	± 0.34	± 0.07	± 0.22	± 0.36	± 0.48	± 0.31	± 0.08	± 0.50	± 0.03
Summer 2014	Mean	0.00	0.22	0.71	0.55	0.73	0.00	0.09	0.48	0.00	0.40
	Standard Deviation	± 0.00	± 0.31	± 0.04	± 0.09	± 0.14	± 0.00	± 0.13	± 0.03	± 0.00	± 0.45
Fall 2014	Mean	0.08	0.09	0.35	0.26	0.40	0.34	0.33	0.68	0.38	0.55
	Standard Deviation	± 0.04	± 0.09	± 0.13	± 0.24	± 0.37	± 0.46	± 0.30	± 0.11	± 0.52	± 0.30
Winter 2014	Mean	0.07	0.48	0.36	0.55	0.31	0.09	0.57	0.51	0.07	0.47
	Standard Deviation	± 0.03	± 0.24	± 0.30	± 0.22	± 0.06	± 0.01	± 0.14	± 0.25	± 0.02	± 0.06

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	NH4-N (mg/L)									
Spring 2013	Mean	0.23	0.35	0.19	0.51	0.20	0.21	0.25	0.19	0.20	0.25
	Standard Deviation	± 0.02	± 0.14	± 0.04	± 0.41	± 0.01	± 0.03	± 0.05	± 0.04	± 0.03	± 0.06
Summer 2013	Mean	0.26	0.27	0.17	0.18	0.18	0.33	0.18	0.16	0.20	0.2
	Standard Deviation	± 0.08	± 0.03	± 0.02	± 0.02	± 0.02	± 0.11	± 0.02	± 0.02	± 0.02	± 0.03
Fall 2013	Mean	0.15	0.16	0.16	0.14	0.10	0.16	0.09	0.12	0.15	0.155
	Standard Deviation	± 0.01	± 0.04	± 0.06	± 0.05	± 0.03	± 0.03	± 0.02	± 0.03	± 0.03	± 0.08
Winter 2013	Mean	0.20	0.25	0.14	0.15	0.11	0.19	0.19	0.12	0.14	0.1233
	Standard Deviation	± 0.06	± 0.25	± 0.05	± 0.05	± 0.04	± 0.03	± 0.16	± 0.04	± 0.03	± 0.03
Sprin 2014	Mean	0.55	0.37	0.19	0.17	0.17	0.21	0.20	0.16	0.18	0.1933
	Standard Deviation	± 0.54	± 0.31	± 0.03	± 0.01	± 0.01	± 0.04	± 0.02	± 0.02	± 0.03	± 0.02
Summer 2014	Mean	0.20	0.19	0.18	0.16	0.11	0.17	0.14	0.22	0.20	0.14
	Standard Deviation	± 0.04	± 0.04	± 0.08	± 0.04	± 0.01	± 0.06	± 0.02	± 0.08	± 0.10	± 0.01
Fall 2014	Mean	0.19	0.16	0.10	0.17	0.12	0.29	0.15	0.12	0.18	0.1233
	Standard Deviation	± 0.03	± 0.02	± 0.01	± 0.06	± 0.02	± 0.11	± 0.02	± 0.03	± 0.07	± 0.03
Winter 2014	Mean	0.17	0.15	0.17	0.16	0.14	0.21	0.19	0.14	0.19	0.1377
	Standard Deviation	± 0.01	± 0.02	± 0.06	± 0.02	± 0.03	± 0.03	± 0.00	± 0.01	± 0.03	± 0.02

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	NO3-N (mg/L)									
Spring 2013	Mean	23.77	0.36	0.18	0.38	0.16	18.31	0.62	0.50	17.06	0.59
	Standard Deviation	± 5.22	± 0.14	± 0.07	± 0.12	± 0.02	± 3.03	± 0.23	± 0.60	± 3.78	± 0.44
Summer 2013	Mean	23.57	1.21	0.48	0.38	0.18	16.72	1.10	0.31	14.05	0.67
	Standard Deviation	± 1.78	± 0.36	± 0.56	± 0.34	± 0.03	± 2.83	± 0.87	± 0.27	± 2.40	± 0.66
Fall 2013	Mean	24.38	5.72	0.83	0.34	0.30	18.51	0.51	0.41	14.68	0.78
	Standard Deviation	± 3.60	± 9.37	± 0.52	± 0.12	± 0.18	± 1.58	± 0.47	± 0.22	± 4.46	± 0.03
Winter 2013	Mean	14.69	0.35	1.09	0.83	0.92	14.01	0.68	0.31	10.87	1.13
	Standard Deviation	± 10.80	± 0.17	± 0.65	± 0.78	± 1.06	± 5.70	± 0.37	± 0.13	± 7.93	± 0.70
Sprin 2014	Mean	12.99	1.13	0.12	0.49	0.79	12.30	0.79	0.10	10.87	0.14
	Standard Deviation	± 9.42	± 1.00	± 0.02	± 0.70	± 1.25	± 9.58	± 0.99	± 0.07	± 8.18	± 0.10
Summer 2014	Mean	22.52	1.20	0.22	0.26	0.15	15.57	1.50	0.18	10.37	0.91
	Standard Deviation	± 0.13	± 1.21	± 0.10	± 0.10	± 0.03	± 1.90	± 0.53	± 0.07	± 2.20	± 0.75
Fall 2014	Mean	20.01	8.96	0.27	6.88	5.76	10.98	8.15	0.30	9.05	0.83
	Standard Deviation	± 0.70	± 12.70	± 0.01	± 10.64	± 9.67	± 8.44	± 12.21	± 0.03	± 8.07	± 0.56
Winter 2014	Mean	17.87	0.59	1.73	0.28	0.94	15.18	0.31	0.54	9.56	0.60
	Standard Deviation	± 3.55	± 0.44	± 2.45	± 0.22	± 0.41	± 4.91	± 0.10	± 0.57	± 5.39	± 0.55

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	NPOC (mg/L)									
Spring 2013	Mean	50.84	26.61	43.19	37.98	82.43	45.26	41.70	37.65	55.34	48.87
	Standard Deviation	± 36.80	± 14.34	± 25.83	± 21.05	± 50.61	± 31.56	± 34.34	± 23.53	± 40.59	± 30.65
Summer 2013	Mean	13.23	16.95	27.99	17.93	79.57	10.35	20.29	26.47	13.67	31.35
	Standard Deviation	± 3.34	± 3.74	± 1.64	± 6.17	± 34.08	± 1.26	± 2.94	± 13.19	± 4.52	± 9.51
Fall 2013	Mean	26.03	21.85	22.29	21.86	35.73	23.11	24.93	26.58	23.36	37.67
	Standard Deviation	± 0.81	± 2.74	± 9.63	± 8.57	± 14.79	± 1.87	± 2.52	± 2.34	± 2.46	± 12.35
Winter 2013	Mean	23.52	19.48	18.01	16.41	22.08	21.97	14.42	21.66	23.02	23.67
	Standard Deviation	± 5.35	± 2.37	± 3.80	± 1.86	± 1.68	± 2.91	± 7.40	± 1.07	± 2.17	± 0.58
Sprin 2014	Mean	67.71	34.36	55.79	46.42	78.68	55.83	56.63	40.46	63.01	66.42
	Standard Deviation	± 33.06	± 16.46	± 26.58	± 39.51	± 41.09	± 29.85	± 28.53	± 14.38	± 30.94	± 30.87
Summer 2014	Mean	56.51	27.57	61.53	25.70	56.59	42.46	53.89	31.01	53.14	49.63
	Standard Deviation	± 39.41	± 18.07	± 51.80	± 10.35	± 35.14	± 29.70	± 48.63	± 19.17	± 22.24	± 33.81
Fall 2014	Mean	13.49	13.75	11.62	13.88	16.96	12.57	23.67	20.31	13.45	25.07
	Standard Deviation	± 1.98	± 1.41	± 1.27	± 2.54	± 2.67	± 1.11	± 6.39	± 4.49	± 2.52	± 6.73
Winter 2014	Mean	13.30	15.39	11.11	14.16	17.72	12.73	15.53	15.92	13.14	15.54
	Standard Deviation	± 0.70	± 2.93	± 0.57	± 2.41	± 8.19	± 1.36	± 4.11	± 1.80	± 1.38	± 2.57

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	pH									
Spring 2013	Mean	7.74	7.85	7.86	7.79	9.11	8.34	8.25	8.07	8.77	8.02
	Standard Deviation	± 0.18	± 0.21	± 0.10	± 0.16	± 0.30	± 0.49	± 0.30	± 0.24	± 0.09	± 0.12
Summer 2013	Mean	8.84	8.89	8.78	8.78	9.60	9.10	8.93	9.17	9.23	8.85
	Standard Deviation	± 0.41	± 0.57	± 0.62	± 0.47	± 0.32	± 0.17	± 0.27	± 0.07	± 0.03	± 0.35
Fall 2013	Mean	7.42	8.16	8.15	8.01	8.13	8.01	8.23	8.24	7.96	8.54
	Standard Deviation	± 0.94	± 0.64	± 0.86	± 0.51	± 0.73	± 0.77	± 0.84	± 0.62	± 0.91	± 0.38
Winter 2013	Mean	7.24	7.64	7.66	7.36	7.69	7.58	7.59	7.33	7.48	7.56
	Standard Deviation	± 0.80	± 0.18	± 0.13	± 0.41	± 0.10	± 0.78	± 0.40	± 0.76	± 0.76	± 0.48
Sprin 2014	Mean	7.19	6.79	7.19	6.79	7.36	7.44	7.47	6.76	7.51	7.77
	Standard Deviation	± 0.81	± 0.68	± 0.61	± 0.63	± 1.14	± 0.74	± 0.68	± 0.87	± 0.65	± 0.26
Summer 2014	Mean	6.88	6.85	6.98	7.11	7.36	7.67	7.39	7.40	7.51	7.40
	Standard Deviation	± 0.04	± 0.37	± 0.22	± 0.15	± 0.13	± 0.81	± 0.23	± 0.08	± 0.92	± 0.01
Fall 2014	Mean	7.38	7.45	7.34	7.40	8.10	8.18	7.90	7.88	8.22	8.13
	Standard Deviation	± 0.46	± 0.27	± 0.21	± 0.26	± 0.35	± 0.26	± 0.23	± 0.19	± 0.31	± 0.05
Winter 2014	Mean	7.73	7.52	7.82	7.70	8.26	8.16	7.49	7.85	8.06	7.18
	Standard Deviation	± 0.07	± 0.34	± 0.13	± 0.06	± 0.20	± 0.03	± 0.96	± 0.09	± 0.29	± 1.48

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	PO4-P									
Spring 2013	Mean	3.86	0.28	0.29	0.21	0.15	3.25	0.41	0.29	3.03	0.43
	Standard Deviation	± 0.74	± 0.12	± 0.14	± 0.04	± 0.08	± 0.34	± 0.05	± 0.17	± 0.36	± 0.08
Summer 2013	Mean	4.02	0.54	0.32	0.29	0.06	3.09	0.79	0.16	3.00	0.69
	Standard Deviation	± 0.56	± 0.07	± 0.08	± 0.08	± 0.04	± 0.05	± 0.09	± 0.11	± 0.09	± 0.08
Fall 2013	Mean	3.74	1.06	0.46	0.34	0.23	3.00	0.50	0.50	2.49	0.74
	Standard Deviation	± 0.55	± 1.28	± 0.07	± 0.22	± 0.10	± 0.40	± 0.19	± 0.13	± 0.84	± 0.36
Winter 2013	Mean	2.38	0.24	0.26	1.15	0.30	2.56	0.91	0.24	2.06	0.34
	Standard Deviation	± 1.51	± 0.05	± 0.11	± 1.48	± 0.34	± 0.72	± 0.19	± 0.07	± 1.22	± 0.15
Sprin 2014	Mean	4.09	0.52	0.33	0.25	0.27	3.64	0.64	0.34	3.22	0.59
	Standard Deviation	± 0.71	± 0.21	± 0.11	± 0.20	± 0.17	± 0.80	± 0.30	± 0.01	± 0.67	± 0.19
Summer 2014	Mean	4.28	0.46	0.32	0.24	0.11	2.86	0.93	0.32	2.23	0.72
	Standard Deviation	± 1.04	± 0.16	± 0.06	± 0.04	± 0.07	± 0.54	± 0.31	± 0.08	± 0.69	± 0.30
Fall 2014	Mean	3.36	0.45	1.66	1.38	1.12	2.11	1.55	0.31	1.74	0.57
	Standard Deviation	± 0.04	± 0.18	± 2.01	± 1.71	± 1.68	± 1.46	± 1.54	± 0.21	± 1.32	± 0.40
Winter 2014	Mean	2.13	0.23	0.39	0.15	0.28	1.28	0.56	0.29	1.37	0.34
	Standard Deviation	± 1.36	± 0.16	± 0.38	± 0.14	± 0.31	± 1.65	± 0.70	± 0.21	± 1.45	± 0.41

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	TN (mg/L)									
Spring 2013	Mean	27.24	1.39	1.15	1.72	2.67	20.14	2.07	1.36	12.23	1.72
	Standard Deviation	± 2.78	± 0.35	± 0.19	± 0.66	± 0.65	± 4.29	± 1.28	± 0.41	± 9.46	± 0.59
Summer 2013	Mean	25.06	2.29	2.06	1.45	3.98	20.60	2.15	2.20	17.54	2.53
	Standard Deviation	± 2.51	± 0.33	± 0.55	± 0.45	± 1.40	± 7.00	± 0.85	± 1.21	± 4.80	± 0.16
Fall 2013	Mean	25.26	6.49	1.71	1.19	1.61	19.77	1.26	1.43	15.36	2.31
	Standard Deviation	± 3.45	± 9.44	± 0.22	± 0.62	± 0.69	± 1.97	± 0.64	± 0.22	± 4.64	± 0.37
Winter 2013	Mean	15.35	0.98	1.69	1.35	1.52	14.60	1.11	1.18	11.23	1.99
	Standard Deviation	± 10.56	± 0.58	± 0.49	± 0.90	± 1.19	± 5.52	± 0.27	± 0.48	± 7.52	± 0.88
Sprin 2014	Mean	21.55	2.10	1.41	1.14	2.46	17.55	1.50	1.24	15.64	1.54
	Standard Deviation	± 1.06	± 0.97	± 0.33	± 0.78	± 1.06	± 4.12	± 0.82	± 0.12	± 0.92	± 0.17
Summer 2014	Mean	21.23	1.56	1.33	0.90	1.11	14.81	1.70	0.77	9.45	1.79
	Standard Deviation	± 0.21	± 0.78	± 0.45	± 0.10	± 0.54	± 1.11	± 0.23	± 0.01	± 0.77	± 0.11
Fall 2014	Mean	21.97	2.03	0.58	1.15	0.87	16.41	1.97	1.49	15.06	2.16
	Standard Deviation	± 1.63	± 0.13	± 0.08	± 0.65	± 0.27	± 3.04	± 1.13	± 0.56	± 3.09	± 0.14
Winter 2014	Mean	19.43	1.31	2.31	0.95	1.61	16.88	1.18	1.24	10.48	1.33
	Standard Deviation	± 3.21	± 0.38	± 2.41	± 0.08	± 0.81	± 5.45	± 0.17	± 0.51	± 5.80	± 0.79

		Site Number									
		80908	80909	80910	80911	80912	80913	80914	80915	80916	80917
Season	Statistic	DOC:DON									
Spring 2013	Mean	34.12	18.97	40.47	19.27	18.94	20.72	124.69	20.16	21.19	36.71
	Standard Deviation	± 34.12	± 18.97	± 40.47	± 19.27	± 18.94	± 20.72	± 124.69	± 20.16	± 21.19	± 36.71
Summer 2013	Mean	5.92	16.13	4.18	6.21	2.80	2.91	19.35	6.06	9.67	3.95
	Standard Deviation	± 5.92	± 16.13	± 4.18	± 6.21	± 2.80	± 2.91	± 19.35	± 6.06	± 9.67	± 3.95
Fall 2013	Mean	7.61	6.56	7.17	13.61	6.79	9.74	22.48	0.78	18.14	0.57
	Standard Deviation	± 7.61	± 6.56	± 7.17	± 13.61	± 6.79	± 9.74	± 22.48	± 0.78	± 18.14	± 0.57
Winter 2013	Mean	18.28	30.35	11.86	32.29	12.23	15.60	24.12	20.84	22.44	9.58
	Standard Deviation	± 18.28	± 30.35	± 11.86	± 32.29	± 12.23	± 15.60	± 24.12	± 20.84	± 22.44	± 9.58
Sprin 2014	Mean	70.28	17.51	32.75	60.44	16.84	3.59	12.66	10.60	17.28	23.99
	Standard Deviation	± 70.28	± 17.51	± 32.75	± 60.44	± 16.84	± 3.59	± 12.66	± 10.60	± 17.28	± 23.99
Summer 2014	Mean	0.00	64.28	78.49	24.40	3.11	0.00	228.18	58.83	0.00	94.05
	Standard Deviation	± 0.00	± 64.28	± 78.49	± 24.40	± 3.11	± 0.00	± 228.18	± 58.83	± 0.00	± 94.05
Fall 2014	Mean	3.18	34.42	39.10	18.25	24.22	6.31	14.10	6.07	11.68	7.55
	Standard Deviation	± 3.18	± 34.42	± 39.10	± 18.25	± 24.22	± 6.31	± 14.10	± 6.07	± 11.68	± 7.55
Winter 2014	Mean	1.93	3.25	1.33	4.31	15.07	2.58	2.90	5.82	12.12	10.32
	Standard Deviation	± 1.93	± 3.25	± 1.33	± 4.31	± 15.07	± 2.58	± 2.90	± 5.82	± 12.12	± 10.32

APPENDIX II

CHEMICAL ANALYSIS OF CARTERS CREEK STUDY (CHAPTER II)

Date	Sample Name	pH	Cond $\mu S\ cm^{-1}$	NO3-N $mg\ L^{-1}$	NH4-N $mg\ L^{-1}$	PO4-P $mg\ L^{-1}$	NPOC $mg\ L^{-1}$	TN $mg\ L^{-1}$	Na+ $mg\ L^{-1}$	K+ $mg\ L^{-1}$	Mg2+ $mg\ L^{-1}$	Ca2+ $mg\ L^{-1}$
2/27/2013	80912	8.97	920	0.16	0.20	0.04	28.62	1.80	174.06	6.94	2.57	14.45
2/27/2013	80908	8.66	1190	22.92	0.21	4.15	13.35	22.90	223.77	10.18	2.12	12.03
2/27/2013	80910	8.47	850	0.15	0.20	0.17	77.82	0.81	151.62	5.18	5.44	30.20
2/27/2013	80913	8.69	1240	22.98	0.22	4.18	13.07	23.12	243.98	11.06	2.12	11.80
2/27/2013	80917	8.41	530	0.21	0.21	0.29	62.48	1.19	114.16	5.76	3.84	28.51
2/27/2013	80909	8.37	440	0.20	0.23	0.11	43.27	1.35	63.45	7.77	3.57	27.96
2/27/2013	80915	8.48	370	0.17	0.20	0.12	41.19	0.95	93.14	5.49	2.19	17.89
2/27/2013	11783	8.35	1280	26.46	0.24	4.63	70.43	27.81	268.53	11.42	2.17	10.57
2/27/2013	11785	8.56	1110	23.85	0.24	4.25	13.48	23.09	235.42	11.34	2.15	10.68
2/27/2013	21259	8.68	1250	21.62	0.22	3.97	74.43	21.56	233.65	11.37	2.14	12.25
2/27/2013	11782	8.57	540	0.18	0.21	0.12	51.21	0.95	108.72	5.52	2.48	16.23
2/27/2013	80911	8.02	690	0.29	0.29	0.10	49.63	1.27	131.56	6.53	6.91	46.81
3/27/2012	80915	8.34	440	0.12	0.16	0.16	39.95	1.00	63.62	4.02	2.23	21.70
3/27/2012	80913	8.27	1640	20.61	0.21	3.54	57.14	22.15	230.44	10.76	2.20	11.07
3/27/2012	80908	7.53	1320	27.97	0.22	4.44	66.59	29.16	268.37	12.21	2.09	8.24
3/27/2012	80911	7.88	1180	0.43	0.98	0.20	44.08	2.41	157.14	6.20	10.03	61.77
3/27/2012	80912	9.39	1050	0.14	0.19	0.14	106.88	3.34	213.68	7.31	2.89	20.62
3/27/2012	80909	8.16	360	0.18	0.20	0.12	32.10	0.98	48.03	4.73	3.20	25.81
3/27/2012	80914	8.49	1360	0.31	0.18	0.48	81.35	0.80	196.10	3.01	2.50	17.62
3/27/2012	80917	8.14	540	0.16	0.18	0.34	54.87	1.08	99.28	4.07	2.58	19.77

Date	Sample Name	pH	Cond µS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}	Na+ mg L^{-1}	K+ mg L^{-1}	Mg2+ mg L^{-1}	Ca2+ mg L^{-1}
3/27/2012	80910	7.93	790	0.11	0.16	0.21	58.63	1.10	89.42	3.51	3.45	25.29
3/27/2012	80916	8.87	1300	18.70	0.19	3.31	72.85	20.70	250.58	10.28	2.60	13.94
3/27/2012	11782	8.26	360	0.15	0.21	0.21	38.97	1.26	46.53	4.21	2.12	15.87
3/27/2012	21259	8.86	1140	18.73	0.20	3.35	53.04	20.34	137.46	6.28	1.31	7.69
3/27/2012	11783	7.79	1390	27.96	0.23	4.37	68.37	30.27	218.37	9.65	1.72	8.55
3/27/2012	11785	8.35	1170	21.64	0.22	3.67	58.45	23.42	218.30	10.18	2.04	11.49
4/22/2013	80913	7.89	1050	19.45	0.24	3.34	69.16	23.05	223.56	10.71	2.07	12.03
4/22/2013	80914	7.82	620	0.88	0.31	0.36	59.47	3.81	121.35	6.49	2.13	16.03
4/22/2013	80917	8.03	660	1.03	0.30	0.48	76.08	2.24	133.12	5.89	2.31	18.87
4/22/2013	80911	7.89	790	0.47	0.30	0.18	55.31	1.66	118.15	4.91	6.42	41.74
4/22/2013	80910	7.75	530	0.19	0.19	0.22	57.56	1.00	85.07	4.02	3.98	34.06
4/22/2013	80912	9.14	960	0.17	0.21	0.07	116.18	2.61	204.62	4.67	1.94	19.43
4/22/2013	80908	7.88	1240	25.42	0.26	4.10	77.15	28.52	248.57	10.67	1.84	10.60
4/22/2013	80916	8.70	1140	19.74	0.23	3.15	84.24	2.03	223.05	9.15	2.24	13.89
4/22/2013	80909	7.75	410	0.50	0.53	0.26	44.38	1.83	64.34	4.96	2.49	21.21
4/22/2013	80915	7.97	480	0.19	0.23	0.22	59.95	1.28	93.59	4.14	2.15	20.11
4/22/2013	21259	8.71	1010	16.65	0.23	2.97	70.77	18.88	212.84	9.88	2.25	13.09
4/22/2013	11782	8.38	450	0.40	0.21	0.25	57.67	1.52	77.02	5.09	3.06	24.84
4/22/2013	11783	7.76	1270	25.53	0.27	4.17	75.30	0.43	251.89	11.13	1.97	10.56
4/22/2013	11785	8.20	1030	19.32	0.25	3.42	69.21	21.79	211.68	10.26	2.06	11.99
5/29/2013	80910	7.90	560	0.25	0.23	0.45	13.37	1.36	106.63	5.73	3.87	30.30
5/29/2013	80915	7.90	330	1.20	0.18	0.48	13.05	1.81	74.00	5.52	2.56	22.96
5/29/2013	80911	7.60	610	0.25	0.24	0.26	14.56	1.10	82.41	6.33	6.44	43.78
5/29/2013	80914	8.30	940	0.65	0.24	0.40	12.48	1.55	190.22	6.74	4.56	30.98

Date	Sample Name	pH	Cond µS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}	Na+ mg L^{-1}	K+ mg L^{-1}	Mg2+ mg L^{-1}	Ca2+ mg L^{-1}
5/29/2013	80912	8.80	610	0.17	0.19	0.23	24.24	2.05	82.93	4.77	2.60	31.82
5/29/2013	80908	7.80	1100	17.93	0.22	3.03	8.79	24.05	252.46	11.06	2.17	13.31
5/29/2013	80909	7.80	260	0.41	0.34	0.39	15.55	1.41	39.43	6.42	3.62	29.92
5/29/2013	80917	7.90	460	0.57	0.27	0.47	15.66	1.83	73.93	7.59	3.15	23.24
5/29/2013	80909	7.70	260	0.34	0.31	0.34	14.41	1.35	31.27	8.09	4.28	29.53
5/29/2013	80913	8.86	830	14.88	0.18	2.88	9.48	15.21	182.24	11.57	2.63	15.70
5/29/2013	80916	8.74	870	12.74	0.18	2.62	8.94	13.97	183.53	8.45	2.75	19.21
5/29/2013	11783	7.70	1100	16.40	0.22	3.17	7.26	21.41	209.34	8.78	1.94	11.86
5/29/2013	21259	8.30	790	16.24	0.20	2.60	8.60	10.78	150.79	8.48	2.96	19.89
5/29/2013	11782	7.80	260	0.57	0.19	0.26	15.58	1.68	33.31	6.73	3.55	27.87
5/29/2013	11785	8.40	870	17.49	0.23	2.87	8.55	13.67	181.55	9.04	2.83	16.83
5/29/2013	80914	8.40	950	0.65	0.26	0.40	13.49	2.10	81.64	7.14	3.17	22.88
6/20/2013	80908	8.38	1165	21.82	0.21	4.42	9.83	22.71	278.82	10.98	2.10	12.11
6/20/2013	80909	8.23	340	1.60	0.29	0.51	13.94	2.19	72.51	6.90	4.11	28.94
6/20/2013	80910	8.11	960	0.20	0.19	0.41	29.12	1.59	183.13	5.72	4.55	29.16
6/20/2013	80911	8.27	730	0.23	0.18	0.20	15.78	0.99	140.32	5.36	5.77	36.94
6/20/2013	80912	9.29	1245	0.22	0.18	0.10	40.23	2.46	327.74	9.29	1.59	9.92
6/20/2013	80913	8.93	1150	13.70	0.40	3.03	9.02	13.15	251.18	9.38	2.10	13.25
6/20/2013	80914	9.14	1630	0.30	0.19	0.76	16.95	1.17	383.28	6.13	3.56	26.72
6/20/2013	80915	9.15	325	0.62	0.17	0.26	15.05	1.41	76.03	5.11	2.31	19.18
6/20/2013	80916	9.21	1240	11.41	0.18	2.91	8.57	12.01	261.04	8.49	2.46	17.02
6/20/2013	80917	8.45	835	1.43	0.23	0.77	21.94	2.55	208.48	7.46	2.74	17.65
6/20/2013	11782	8.44	320	0.90	0.23	0.34	15.39	1.95	62.41	6.99	4.00	28.30
6/20/2013	11783	8.25	1195	21.60	0.22	4.37	8.98	22.09	265.14	11.14	2.06	10.98

Date	Sample Name	pH	Cond µS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}	Na+ mg L^{-1}	K+ mg L^{-1}	Mg2+ mg L^{-1}	Ca2+ mg L^{-1}
6/20/2013	11785	8.71	1060	14.46	0.65	3.02	10.27	15.23	247.89	11.93	2.33	13.80
6/20/2013	21259	9.04	1105	12.95	0.26	2.76	10.39	13.16	242.08	9.46	2.05	12.79
7/31/2013	80908	8.99	930	25.38	0.23	3.38	13.35	27.70	288.03	12.69	2.19	11.82
7/31/2013	80909	9.23	390	1.13	0.29	0.62	15.78	2.02	126.82	6.42	2.57	18.07
7/31/2013	80910	8.91	820	0.11	0.16	0.25	26.11	1.93	245.77	5.80	3.06	20.91
7/31/2013	80911	8.88	570	0.77	0.20	0.35	13.13	1.48	167.37	4.02	2.53	18.48
7/31/2013	80912	9.92	1370	0.16	0.19	0.05	100.26	5.22	427.63	9.36	0.92	9.94
7/31/2013	80913	9.11	850	19.30	0.20	3.12	11.52	21.60	252.66	9.68	2.02	11.77
7/31/2013	80914	8.62	1280	2.03	0.20	0.73	21.42	2.64	385.92	8.25	3.90	26.48
7/31/2013	80915	9.25	350	0.19	0.17	0.18	23.45	1.60	107.20	5.10	2.23	16.65
7/31/2013	80916	9.21	930	16.11	0.21	3.02	15.23	20.61	264.66	9.12	1.90	13.57
7/31/2013	80917	9	740	0.35	0.20	0.70	31.16	2.37	234.43	5.36	1.91	16.02
7/31/2013	11782	9.17	450	2.36	0.21	0.79	20.01	3.91	124.37	7.12	2.78	17.05
7/31/2013	11783	8.86	960	26.30	0.23	4.31	10.80	31.91	293.09	12.23	2.12	11.00
7/31/2013	11785	8.93	790	19.22	0.20	3.07	11.00	24.14	245.85	9.55	2.11	12.01
7/31/2013	21259	9.32	860	15.42	0.24	2.59	14.15	19.35	257.87	10.07	2.05	12.52
8/29/2013	80915	9.12	920	0.11	0.14	0.04	40.91	3.60	214.99	7.32	1.82	9.10
8/29/2013	80913	9.26	1240	17.17	0.39	3.11	10.52	27.05	278.58	10.27	2.07	12.38
8/29/2013	80916	9.27	1400	14.63	0.21	3.08	17.20	20.01	324.81	14.71	2.48	9.56
8/29/2013	80909	9.22	800	0.90	0.23	0.49	21.14	2.66	155.88	6.00	1.83	10.70
8/29/2013	80914	9.02	2040	0.96	0.16	0.89	22.50	2.64	441.52	6.32	3.49	20.12
8/29/2013	80908	9.16	1330	23.50	0.35	4.25	16.51	24.77	293.23	10.55	1.93	10.42
8/29/2013	80910	9.32	1120	1.12	0.15	0.31	28.73	2.66	279.29	5.50	2.55	13.26

Date	Sample Name	pH	Cond µS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}	Na+ mg L^{-1}	K+ mg L^{-1}	Mg2+ mg L^{-1}	Ca2+ mg L^{-1}
8/29/2013	80912	9.59	1740	0.16	0.16	0.03	98.22	4.27	418.87	8.22	1.25	8.83
8/29/2013	80911	9.2	750	0.14	0.16	0.32	24.89	1.88	159.09	5.12	3.66	21.88
8/29/2013	80917	9.11	1460	0.23	0.17	0.61	40.96	2.68	335.49	6.68	2.06	14.99
8/29/2013	21259	9.14	1270	15.48	0.19	3.06	10.19	24.37	275.88	9.86	2.04	11.86
8/29/2013	11783	9.29	1340	24.04	0.36	4.33	15.68	28.03	299.87	16.99	2.71	10.08
8/29/2013	11785	9.08	1210	19.11	0.22	3.33	10.45	28.31	274.47	10.13	1.94	11.24
8/29/2013	11782	9.26	1390	13.77	0.23	3.25	14.01	21.99	311.23	14.44	2.70	13.18
9/23/2013	80909	8.65	200	2.71	0.20	0.78	18.24	3.30	69.14	6.33	2.59	17.22
9/23/2013	80916	8.7	890	14.43	0.15	2.64	26.19	15.10	230.66	9.36	2.19	15.57
9/23/2013	80910	8.84	590	0.23	0.16	0.54	33.28	1.47	147.97	12.23	3.21	25.70
9/23/2013	80911	8.36	490	0.44	0.16	0.59	30.60	1.80	104.63	5.89	3.75	30.31
9/23/2013	80915	8.59	290	0.28	0.13	0.64	30.08	1.44	76.86	4.96	1.96	17.56
9/23/2013	80912	8.68	750	0.22	0.08	0.13	51.43	2.41	204.20	7.57	1.83	16.06
9/23/2013	80917	8.81	630	0.76	0.10	0.99	46.40	2.57	195.14	6.03	2.02	16.47
9/23/2013	80914	9.06	570	1.05	0.09	0.56	22.41	1.96	149.86	5.23	2.75	21.29
9/23/2013	80913	8.59	820	19.62	0.16	3.21	23.42	20.80	221.07	10.42	2.09	12.88
9/23/2013	80908	8.51	970	28.53	0.15	4.37	25.09	29.24	290.04	11.30	1.92	11.87
9/23/2013	11783	8.48	1020	28.96	0.16	4.34	24.08	29.52	270.19	11.18	2.11	12.80
9/23/2013	21259	8.9	760	15.72	0.16	2.86	22.63	16.25	209.32	9.46	2.26	15.83
9/23/2013	11785	8.89	800	18.69	0.17	3.15	24.04	19.63	215.68	9.96	2.13	13.89
9/23/2013	11782	8.54	320	0.41	0.13	0.37	24.72	1.41	92.95	6.07	2.50	16.10
11/4/2013	80912	8.41	280	0.51	0.13	0.33	22.07	1.26	75.39	5.13	3.61	30.14
11/4/2013	80914	8.26	230	0.19	0.11	0.28	27.45	1.09	53.26	4.88	3.22	29.09

Date	Sample Name	pH	Cond µS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}	Na+ mg L^{-1}	K+ mg L^{-1}	Mg2+ mg L^{-1}	Ca2+ mg L^{-1}
11/4/2013	80915	8.58	170	0.69	0.14	0.53	25.15	1.69	58.06	5.49	2.48	21.64
11/4/2013	80910	8.43	230	1.21	0.21	0.43	18.27	1.89	53.99	4.64	3.20	27.17
11/4/2013	80915	8.46	190	0.47	0.14	0.49	25.45	1.44	47.38	5.42	2.66	22.53
11/4/2013	80917	8.27	270	0.80	0.21	0.48	28.93	2.05	78.44	5.28	2.63	19.52
11/4/2013	80909	8.49	190	0.31	0.16	0.30	22.35	1.15	23.36	5.51	4.19	28.83
11/4/2013	80916	8.23	490	10.35	0.18	1.58	21.78	10.86	146.62	7.47	3.32	24.16
11/4/2013	80913	8.29	650	16.70	0.18	2.53	21.11	17.50	190.88	8.91	2.64	18.56
11/4/2013	80909	8.27	760	19.67	0.17	2.95	24.89	20.56	233.30	9.92	2.91	17.51
11/4/2013	80911	8.25	340	0.37	0.17	0.28	21.53	1.22	65.77	5.52	5.83	44.43
11/4/2013	11785	8.34	560	15.48	0.26	2.27	20.30	16.14	172.76	8.59	2.84	20.73
11/4/2013	21259	8.05	510	13.39	0.19	1.93	19.10	13.62	150.43	8.17	2.84	21.12
11/4/2013	11783	8.19	750	20.80	0.17	3.10	11.91	21.26	231.09	9.55	2.53	18.19
11/4/2013	11782	8.45	170	0.33	0.12	0.29	22.26	1.14	29.81	5.19	3.73	28.72
11/20/2013	80908	6.87	1420	22.50	0.16	3.41	26.53	23.39	298.62	11.71	2.58	12.65
11/20/2013	80910	7.18	550	1.04	0.10	0.40	15.32	1.76	85.59	6.43	4.38	35.32
11/20/2013	80908	6.89	1390	22.11	0.15	3.44	26.46	23.16	312.31	12.40	2.50	13.74
11/20/2013	80912	7.31	980	0.17	0.08	0.23	33.68	1.17	157.78	6.05	4.33	33.54
11/20/2013	80909	7.22	430	0.20	0.11	0.22	21.93	0.95	58.23	6.89	6.33	45.07
11/20/2013	80914	7.38	1200	0.29	0.08	0.65	24.93	0.72	240.12	6.76	5.14	35.57
11/20/2013	80915	7.31	430	0.21	0.08	0.33	25.64	1.15	62.90	9.29	3.60	26.86
11/20/2013	80911	7.42	570	0.21	0.08	0.16	13.46	0.56	73.23	5.50	5.24	37.05
11/20/2013	80916	6.94	1270	19.26	0.13	3.24	22.11	20.12	248.38	11.14	2.75	16.50
11/20/2013	80913	7.14	1250	19.21	0.13	3.25	24.81	21.01	235.10	11.37	2.54	17.28

Date	Sample Name	pH	Cond µS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}	Na+ mg L^{-1}	K+ mg L^{-1}	Mg2+ mg L^{-1}	Ca2+ mg L^{-1}
11/20/2013	11783	6.87	1400	22.19	0.18	3.40	24.06	22.63	290.77	11.53	2.41	15.61
11/20/2013	21259	7.32	1110	16.59	0.18	2.94	20.80	17.42	186.32	9.70	2.53	15.84
11/20/2013	11782	7.33	380	0.13	0.07	0.22	20.76	0.84	47.02	5.49	4.30	31.56
11/20/2013	11785	7.25	1190	20.33	0.15	3.26	21.37	21.15	210.46	10.21	2.67	16.85
12/18/2013	80915	7.82	350	0.16	0.08	0.17	22.73	0.63	97.53	4.94	5.35	41.59
12/18/2013	80912	7.76	470	0.17	0.08	0.06	23.27	0.68	124.23	4.61	5.56	43.69
12/18/2013	80914	7.94	810	1.04	0.09	1.00	9.55	1.02	266.21	6.24	2.55	17.41
12/18/2013	80908	7.72	910	23.28	0.17	3.40	28.31	23.15	287.19	11.97	2.88	16.61
12/18/2013	80916	7.88	820	15.72	0.12	2.72	23.92	15.28	235.23	8.81	3.15	19.91
12/18/2013	80917	7.85	410	0.44	0.12	0.16	24.20	1.11	114.84	5.11	4.38	32.93
12/18/2013	21259	7.83	810	17.07	0.11	3.44	21.81	16.44	281.75	11.84	2.51	13.90
12/18/2013	80913	8	760	16.79	0.17	2.89	22.63	16.57	237.51	10.11	3.04	19.69
12/18/2013	80911	7.58	990	0.33	0.09	2.86	17.79	0.62	241.84	10.08	2.68	16.87
12/18/2013	80910	7.72	450	1.16	0.12	0.14	13.63	1.55	192.10	6.25	15.05	92.39
12/18/2013	80909	7.78	360	0.30	0.11	0.29	21.50	0.66	131.55	6.60	5.90	39.74
12/18/2013	11783	7.85	930	24.30	0.17	0.13	24.02	23.08	99.81	4.65	5.09	37.92
12/18/2013	11785	7.92	810	17.70	0.12	2.92	23.24	17.35	252.75	10.45	3.37	20.22
12/18/2013	11782	7.82	410	1.03	0.09	0.28	22.02	1.33	92.22	4.89	5.30	40.22
1/29/2014	11782	7.84	410	1.35	0.08	0.37	22.09	2.06	79.77	5.40	4.79	36.98
1/29/2014	11785	7.86	1040	16.59	0.12	2.91	22.86	17.86	220.18	9.64	3.57	22.76
1/29/2014	21259	7.89	1030	16.97	0.14	2.97	27.12	18.87	237.83	10.45	3.03	17.94
1/29/2014	80915	7.72	480	0.36	0.12	0.24	21.66	1.54	103.21	5.13	3.31	29.16
1/29/2014	80910	7.76	450	1.70	0.11	0.35	20.45	2.23	89.01	4.73	4.54	36.42

Date	Sample Name	pH	Cond µS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}	Na+ mg L^{-1}	K+ mg L^{-1}	Mg2+ mg L^{-1}	Ca2+ mg L^{-1}
1/29/2014	80908	7.68	1060	18.21	0.15	3.09	24.51	19.57	240.40	9.89	2.59	17.09
1/29/2014	80917	7.82	460	1.83	0.10	0.41	23.77	2.87	107.32	5.51	3.47	24.38
1/29/2014	80911	7.61	940	1.73	0.18	0.34	17.14	2.36	143.18	5.61	11.76	75.10
1/29/2014	80909	7.7	480	0.21	0.10	0.21	20.08	0.62	97.16	4.77	5.05	39.83
1/29/2014	11783	7.67	1060	18.06	0.15	3.02	25.85	19.32	241.98	10.04	2.96	17.13
1/29/2014	80914	7.67	1100	0.30	0.10	1.03	22.94	0.89	232.29	6.84	5.69	39.56
1/29/2014	80913	8.05	1040	17.79	0.22	3.06	24.50	18.86	249.21	10.30	2.93	17.68
1/29/2014	80916	7.95	1010	15.18	0.12	2.81	24.60	15.86	237.82	9.58	3.05	18.99
2/26/2014	80915	6.45	590	0.41	0.16	0.30	20.59	1.36	96.27	4.82	3.13	29.67
2/26/2014	80916	6.6	690	1.72	0.18	0.66	20.55	2.56	122.28	5.67	3.87	26.68
2/26/2014	80908	6.31	480	2.57	0.27	0.65	17.74	3.33	86.32	5.07	3.18	23.74
2/26/2014	80913	6.68	940	7.45	0.17	1.74	18.79	8.36	167.51	7.51	3.96	25.36
2/26/2014	80917	7	570	1.11	0.15	0.44	23.05	1.99	102.20	4.72	3.54	25.01
2/26/2014	80911	6.89	840	0.42	0.18	0.26	14.29	1.07	114.03	5.23	7.03	47.09
2/26/2014	80914	7.16	770	0.71	0.38	0.69	10.78	1.41	131.61	4.49	3.06	21.91
2/26/2014	11782	7.14	550	0.33	0.09	0.18	15.88	1.02	97.39	4.82	3.94	31.09
2/26/2014	11783	7.22	600	6.17	0.21	1.45	18.36	6.93	115.71	6.37	2.85	22.82
2/26/2014	21259	7.63	1150	16.88	0.21	3.42	19.36	18.49	246.37	11.24	2.98	14.85
2/26/2014	11785	7.43	1110	12.68	0.19	3.24	19.17	14.28	223.86	9.91	4.52	27.24
2/26/2014	80912	7.62	650	1.67	0.13	0.54	20.89	2.36	98.48	4.43	3.63	27.24
2/26/2014	80910	7.51	370	0.41	0.20	0.30	19.95	1.29	63.07	4.66	3.36	31.59
2/26/2014	80909	7.44	520	0.53	0.53	0.21	16.87	1.65	84.76	6.20	4.42	31.70
3/26/2014	11782	5.94	420	0.14	0.20	0.18	20.09	0.82	50.69	3.77	3.61	28.56

Date	Sample Name	pH	Cond µS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}	Na+ mg L^{-1}	K+ mg L^{-1}	Mg2+ mg L^{-1}	Ca2+ mg L^{-1}
3/26/2014	80911	6.15	1150	0.15	0.18	0.11	14.74	0.71	129.50	5.10	14.63	88.03
3/26/2014	80915	6.43	400	0.14	0.18	0.35	24.00	1.16	68.95	5.42	3.28	29.29
3/26/2014	11783	6.67	1340	19.37	0.27	4.59	26.60	23.11	280.67	12.50	2.70	14.72
3/26/2014	80913	8.1	1230	18.05	0.24	4.14	23.23	21.64	257.62	12.72	3.44	18.36
3/26/2014	80912	8.07	1060	2.24	0.18	0.45	36.98	3.21	231.44	6.60	5.93	24.21
3/26/2014	11785	8.08	1150	18.07	0.23	3.92	25.50	21.38	265.59	11.51	3.55	16.87
3/26/2014	80916	8.19	1260	15.15	0.20	3.32	27.88	16.21	239.40	9.77	3.19	18.16
3/26/2014	21259	8.12	1250	17.90	0.19	3.42	26.17	18.61	253.58	11.13	3.31	18.51
3/26/2014	80914	7.97	1430	1.91	0.19	0.84	26.45	2.39	259.24	6.77	7.55	47.24
3/26/2014	80917	8.07	670	0.16	0.18	0.38	35.73	1.59	147.26	6.65	4.95	31.98
3/26/2014	80910	7.67	1130	0.12	0.22	0.21	30.05	1.22	170.55	5.21	9.79	59.47
3/26/2014	80908	8.05	1290	18.32	0.27	4.40	29.69	21.79	290.55	12.19	3.24	16.92
3/26/2014	80909	7.56	580	1.98	0.19	0.56	15.43	2.59	91.90	6.07	5.72	c

Date	Sample Name	pH	Cond uS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}
4/30/2014	80908	6.44	1910	18.54	1.17	4.60	89.62	20.40
4/30/2014	80909	6.56	640	1.38	0.72	0.71	45.29	2.73
4/30/2014	80910	6.5	1570	0.14	0.19	0.35	83.13	1.23
4/30/2014	80912	7.96	1950	0.12	0.16	0.24	119.13	2.92
4/30/2014	80914	7.74	2230	0.43	0.22	0.78	83.15	1.36
4/30/2014	80915	7.75	710	0.14	0.16	0.33	46.79	1.38
4/30/2014	80917	7.63	980	0.22	0.18	0.63	97.46	1.68
4/30/2014	21259	8.39	1180	14.84	0.17	3.33	82.26	15.34

Date	Sample Name	pH	Cond uS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}
4/30/2014	11782	8.05	430	0.59	0.17	0.37	48.16	1.66
4/30/2014	11783	8.07	1440	17.97	1.07	4.37	92.10	18.78
4/30/2014	11785	8.02	1030	17.73	0.30	4.16	78.53	18.18
4/30/2014	80913	6.64	1180	17.62	0.23	4.07	81.83	17.60
4/30/2014	80916	6.9	1230	16.01	0.20	3.83	86.22	16.12
4/30/2014	80911	6.81	1290	1.30	0.16	0.47	90.70	2.04
6/4/2014	80912	6.04	770	0.02	0.16	0.12	79.93	1.24
6/4/2014	80915	6.1	270	0.02	0.14	0.34	50.58	1.18
6/4/2014	80909	6.25	310	0.02	0.19	0.29	42.36	0.98
6/4/2014	80914	6.7	890	0.02	0.19	0.30	60.30	0.76
6/4/2014	80908	7.09	1200	2.12	0.21	3.28	83.83	22.47
6/4/2014	80916	7.44	1010	1.44	0.15	2.51	74.92	14.58
6/4/2014	80913	7.59	1025	1.24	0.16	2.72	62.43	13.41
6/4/2014	80910	7.41	530	0.11	0.17	0.42	54.19	1.79
6/4/2014	80911	7.4	460	0.02	0.16	0.16	33.83	0.66
6/4/2014	80917	7.61	630	0.03	0.22	0.75	66.08	1.35
6/4/2014	11783	7.56	1190	2.10	0.22	3.26	83.19	20.74
6/4/2014	11782	7.52	300	0.17	0.14	0.46	40.79	2.22
6/4/2014	21259	7.72	920	1.38	0.14	2.18	65.60	14.59
6/4/2014	11785	7.75	970	1.69	0.15	2.72	66.60	17.37
6/25/2014	80908	6.9	1550	22.43	0.22	3.54	84.37	21.37
6/25/2014	11783	6.9	1560	22.48	0.22	3.28	86.37	21.81
6/25/2014	11785	6.95	990	11.85	0.24	2.02	56.28	11.79
6/25/2014	80914	7.23	1610	1.12	0.15	0.71	88.28	1.54

Date	Sample Name	pH	Cond uS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}
6/25/2014	80910	7.13	1290	0.15	0.12	0.28	98.16	1.01
6/25/2014	80912	7.45	880	0.13	0.12	0.06	81.43	1.49
6/25/2014	21259	7.37	770	4.70	0.24	0.90	48.32	4.95
6/25/2014	80909	7.11	410	0.34	0.22	0.34	40.34	1.00
6/25/2014	11782	7.19	590	0.25	0.14	0.30	52.44	0.95
6/25/2014	80915	7.34	440	0.13	0.27	0.26	44.56	0.76
6/25/2014	80911	7.21	530	0.33	0.18	0.21	33.02	0.97
6/25/2014	80917	7.39	723	0.38	0.15	0.51	73.53	1.86
6/25/2014	80913	7.09	1030	14.22	0.21	2.48	63.46	14.02
6/25/2014	80916	6.86	1000	8.81	0.27	1.74	68.86	8.90
7/30/2014	80908	6.85	1310	22.61	0.17	5.01	28.64	21.08
7/30/2014	80909	6.59	520	2.05	0.16	0.57	14.79	2.11
7/30/2014	80910	6.82	510	0.29	0.24	0.36	24.90	1.65
7/30/2014	80911	7	940	0.19	0.13	0.27	18.38	0.83
7/30/2014	80912	7.27	590	0.17	0.10	0.16	31.74	0.72
7/30/2014	80913	8.24	1145	16.91	0.12	3.24	21.46	15.59
7/30/2014	80914	7.55	1570	1.87	0.12	1.15	19.50	1.86
7/30/2014	80915	7.46	430	0.23	0.16	0.37	17.45	0.78
7/30/2014	80916	8.16	1140	11.92	0.13	2.71	37.41	9.99
7/30/2014	80917	7.4	760	1.44	0.13	0.93	25.72	1.71
7/30/2014	11783	7.46	1330	22.14	0.17	4.86	32.57	19.98
7/30/2014	11782	7.33	430	2.05	0.12	0.57	23.14	2.15
7/30/2014	11785	7.78	1120	17.79	0.14	3.49	35.75	15.43

Date	Sample Name	pH	Cond uS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}
7/30/2014	21259	7.84	1120	17.08	0.13	3.32	36.91	14.36
9/3/2014	80908	7.05	1100	19.51	0.17	3.33	12.09	20.81
9/3/2014	80909	7.48	590	1.80	0.16	0.59	15.37	2.18
9/3/2014	80910	7.49	730	0.27	0.11	0.24	12.52	0.52
9/3/2014	80911	7.27	470	0.32	0.12	0.32	13.32	0.83
9/3/2014	80912	7.72	730	0.23	0.09	0.06	13.88	0.61
9/3/2014	80913	7.88	980	13.30	0.38	2.77	12.78	14.63
9/3/2014	80914	7.63	590	1.82	0.14	0.69	31.05	3.28
9/3/2014	80915	7.65	520	0.29	0.11	0.28	21.28	1.31
9/3/2014	80916	7.98	1010	10.87	0.21	2.33	15.19	11.72
9/3/2014	80917	8.1	1060	1.31	0.13	0.81	17.42	2.00
9/3/2014	11782	7.88	370	0.51	0.14	0.31	18.15	1.47
9/3/2014	11783	7.71	1080	18.09	0.17	3.21	8.92	19.57
9/3/2014	11785	7.92	930	14.57	0.30	2.96	9.71	16.02
9/3/2014	21259	7.98	850	11.47	0.31	2.44	12.61	12.34
10/1/2014	80909	7.16	350	23.62	0.15	0.24	12.91	1.96
10/1/2014	80910	7.19	580	0.26	0.09	3.08	10.72	0.63
10/1/2014	80911	7.23	630	19.15	0.23	3.35	11.67	0.72
10/1/2014	80912	8.17	840	16.93	0.13	3.06	18.65	1.14
10/1/2014	80914	8.06	1330	22.22	0.17	3.32	19.79	1.27
10/1/2014	80913	8.35	1030	1.62	0.17	0.44	11.37	14.67
10/1/2014	80915	8.07	420	0.29	0.10	0.10	23.45	2.25
10/1/2014	80916	8.57	1060	0.23	0.10	0.22	14.61	15.63

Date	Sample Name	pH	Cond uS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}
10/1/2014	80917	8.18	790	0.21	0.09	0.10	30.05	2.24
10/1/2014	11782	7.94	360	0.45	0.10	0.80	17.08	1.12
10/1/2014	11783	7.96	1120	16.59	0.41	3.17	11.33	17.38
10/1/2014	11785	8.11	960	0.82	0.12	0.45	8.18	19.15
10/1/2014	21259	8.45	990	15.29	0.25	2.84	11.59	15.86
11/10/2014	21259	8	1290	16.38	0.26	2.70	13.10	18.08
11/10/2014	80916	8.1	1420	16.05	0.24	2.66	10.56	17.83
11/10/2014	11782	8	390	0.99	0.14	0.41	15.87	1.67
11/10/2014	11783	7.8	1590	20.89	0.20	3.37	15.95	22.66
11/10/2014	80913	8.3	1470	18.02	0.33	3.12	13.57	19.92
11/10/2014	80911	7.7	770	1.16	0.16	0.48	16.66	1.90
11/10/2014	11785	8.3	1380	17.32	0.21	2.85	14.82	18.66
11/10/2014	80917	8.1	870	0.96	0.15	0.79	27.75	2.25
11/10/2014	80915	8	460	0.35	0.16	0.60	22.78	1.48
11/10/2014	80914	8	900	0.41	0.15	0.63	20.18	1.37
11/10/2014	80912	8.4	720	0.12	0.13	0.25	18.35	0.86
11/10/2014	80908	7.7	1620	20.50	0.21	3.39	14.89	23.12
11/10/2014	80909	7.7	420	1.45	0.18	0.51	12.96	1.96
11/10/2014	80915	7.8	480	0.28	0.12	0.27	13.71	0.92
12/3/2014	80909	7.25	326	0.10	0.1277	0.38	15.25	0.87
12/3/2014	80912	8.44	808	1.40	0.1715	0.63	27.12	2.52
12/3/2014	80913	8.2	1223	20.68	0.2373	3.19	13.23	23.03
12/3/2014	11785	8.36	1105	18.15	0.2275	3.02	13.62	19.63

Date	Sample Name	pH	Cond uS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}
12/3/2014	80916	8.34	1254	15.11	0.1728	3.01	12.69	16.56
12/3/2014	21259	8.29	1090	18.12	0.1542	3.03	14.70	19.99
12/3/2014	11783	7.88	1312	21.71	0.1731	3.28	13.12	23.46
12/3/2014	80908	7.79	1310	21.23	0.1726	3.31	12.81	22.56
12/3/2014	11782	7.62	293	0.10	0.1254	0.34	16.10	0.78
12/3/2014	80910	7.7	579	0.10	0.1232	0.31	11.62	0.69
12/3/2014	80911	7.66	805	0.12	0.1479	0.25	15.86	0.89
12/3/2014	80914	8.17	1457	0.24	0.1917	1.06	18.43	1.30
12/4/2014	80917	8.32	552	1.23	0.1232	0.81	15.67	2.24
12/5/2014	80915	7.96	428	0.14	0.1232	0.52	17.74	1.03
1/7/2015	21259	7.99	721	9.79	0.20	0.258	12.09	10.35
1/7/2015	11782	7.52	247	0.45	0.16	0.054	10.21	0.91
1/7/2015	80910	7.8	317	0.54	0.24	0.056	10.50	1.16
1/7/2015	80911	7.74	642	0.43	0.18	0.047	12.45	1.01
1/7/2015	11783	7.84	1153	18.07	0.18	0.619	13.66	18.80
1/7/2015	11785	7.96	788	11.53	0.18	0.304	11.95	12.39
1/7/2015	80908	7.65	719	18.23	0.17	0.646	12.99	19.58
1/7/2015	80915	7.81	212.5	1.19	0.15	0.125	14.14	1.82
1/7/2015	80916	7.76	800	9.21	0.18	0.26	12.04	9.87
1/7/2015	80912	8.31	388	0.83	0.12	0.056	12.10	1.34
1/7/2015	80917	5.5	924	0.27	0.13	0.047	12.91	0.81
1/7/2015	80909	7.9	250	0.73	0.15	0.067	18.39	1.56
1/7/2015	80914	6.81	609	0.38	0.19	0.065	12.62	1.06

Date	Sample Name	pH	Cond uS cm^{-1}	NO3-N mg L^{-1}	NH4-N mg L^{-1}	PO4-P mg L^{-1}	NPOC mg L^{-1}	TN mg L^{-1}
1/7/2015	80913	8.14	834	13.61	0.18	0.435	11.19	14.92
2/4/2015	11785	8.13	1087	10.6167	0.2389	1.8740	13.75	12.01
2/4/2015	80916	8.08	919.5	4.3452	0.2207	0.8492	14.68	5.00
2/4/2015	80913	8.15	1019	11.2546	0.2083	0.2245	13.78	12.68
2/4/2015	11782	8.03	551.9	0.7922	0.1501	2.0258	13.18	1.30
2/4/2015	80917	7.71	686.7	0.2916	0.1598	0.1483	18.04	0.93
2/4/2015	11783	7.77	1105	13.5533	0.1451	2.4408	18.85	15.63
2/4/2015	80909	7.4	446.9	0.9367	0.1573	0.2319	12.54	1.51
2/4/2015	80915	7.79	445.6	0.2763	0.1365	0.2140	15.88	0.87
2/4/2015	21259	7.9	1101	7.6667	0.2131	1.5018	13.82	8.69
2/4/2015	80912	8.04	605.9	0.5993	0.1243	0.1432	13.95	0.97
2/4/2015	80908	7.74	1100	14.1607	0.1573	2.4227	14.10	16.15
2/4/2015	80910	7.96	593.1	4.5381	0.1363	0.8095	11.21	5.08

APPENDIX III

E. coli CONCENTRATIONS FROM ROUTINE SITES

	E. coli CFU/ 100mL^{-1}			
Date	11782	11783	11785	21259
2/27/2013	161	270	690	310
3/27/2013	136	261	620	480
4/22/2013	120	272	680	500
5/29/2013	241	309	298	210
6/19/2013	110	400	500	100
7/31/2013	84	1500	410	180
8/28/2013	128	1100	630	350
9/25/2013	530	670	740	730
11/4/2013	208	560	620	530
11/20/2013	64	272	620	330
12/18/2013	60	610	253	144
1/29/2014	116	230	300	500
2/28/2014	7400	4500	2300	820
3/26/2014	16	254	730	460
4/30/2014	100	295	660	400
6/4/2014	180	320	530	136
6/25/2014	104	350	690	1900
7/30/2014	88	370	500	261
9/3/2014	220	470	720	580
10/7/2014	48	360	770	288
11/10/2014	116	550	860	570

	E. coli CFU/ 100mL^{-1}			
Date	11782	11783	11785	21259
12/5/2014	84	184	490	630
1/7/2015	1200	140	260	770
2/4/2015	363	920	1100	640

APPENDIX IV

E. coli CONCENTRATIONS FROM RECONNIANSSANCE SITES

	E. coli MPN 100mL $^{-1}$									
Date	80908	80909	80910	80912	80915	80911	80913	80914	80916	80917
2/27/2013	307.6	231	686.7	816.4	6.1	1986	687	219	483	61
3/27/2013	275.5	178.2	38.8	2419.6	2	62	770	160	461	48
4/22/2013	276	178	249	387	14	66.3	980.4	238.2	325.5	185
5/29/2013	261.3	1046.2	2419.6	88.4	104.6	186	387	1553	579	210
6/19/2013	307.6	579.4	307.6	727	2	88	1203	517	228	281
7/31/2013	980.4	152.9	2419.6	387.3	66.3	387	488	921	461	866
8/28/2013	1203.3	488.4	1732.9	1046.2	13.4	276	908	1120	613	91
9/25/2013	169.4	110	248.9	2419.6	290.9	173	1986	613	461	548
11/4/2013	365.4	193.5	307.6	313	105	123.4	613.1	410.6	260.3	435.2
11/20/2013	325.5	272.3	290.9	307.6	35.9	613.1	980.4	114.5	461.1	122.3
12/18/2013	461.1	93.3	44.6	50.5	14.5	866	980	38	579	55
1/29/2014	260.3	81.6	260.3	313	79.4	64	727	146	179	166
2/28/2014	2419.6	1986.3	2419.6	2419.6	2420	2420	2420	2420	2420	2420
3/26/2014	191.8	313	44.3	191.8	36.9	16	866	517	2420	73
4/30/2014	248.1	15.8	38.9	66.3	4.1	260	727	326	517	50
6/4/2014	488.4	770.1	1046	1986.3	124.6	115	921	118	461	98
6/25/2014	488.4	151.5	2419.6	2419.6	16.9	1553	1120	411	387	517
7/30/2014	517.2	109.2	365.4	980.4	51.2	224.7	613.1	435.2	410.6	161.6
9/3/2014	547.5	47.3	1299.7	143.9	23.1	435	1300	219	649	1120
10/7/2014	435.2	365.4	461.1	344.8	1120	84	1733	548	727	70
11/10/2014	435.2	127.4	228.2	360.9	193.5	76	866	547	291	105

	E. coli MPN 100mL $^{-1}$									
Date	80908	80909	80910	80912	80915	80911	80913	80914	80916	80917
12/5/2014	167	167	37.3	70.3	290.9	81	82	86	649	59
1/7/2015	517.2	1119.9	387.3	1986.3	1986	727	436	687	727	96
2/4/2015	1413.6	307.6	648.8	1553.1	2420	2419	170	727	727	1553

APPENDIX V

SOIL SOLUTION NUTRIENT CONCENTRATIONS RETRIEVED FROM LYSIMETERS FROM THE GRAVE STUDY

Date Collected	NAWA	Lysimeter	Downslope (m)	pH	Cond	NO_3-N	NH_4-N	PO4-P	DOC	TDN	DON
						mg L^{-1}					
4/6/2014	6138	B1-14	14	6.89	270	0.17	0.16	0.48	40.60	0.46	0.13
5/28/2014	6224	B1-14	14			0.15	0.14	1.05	159.81	3.05	2.76
6/25/2014	6250	B1-14	14	7.51	840	0.12	12.37		78.39	98.79	86.30
4/6/2014	6151	B12R-1.5	1	7.52	910	0.17	0.19	0.15	70.71	1.55	1.19
6/25/2014	6243	B12R-4.5	3	7.56	640	0.12	0.13		130.08	3.70	3.44
4/6/2014	6137	B1-9	9	6.63	670	0.23	0.17	1.31	90.34	2.91	2.51
6/26/2014	6255	B1-9	9	7.06	570	short	short	short	short	short	short
4/6/2014	6159	B2-1	1	7.66	1220	0.16	0.17	0.18	108.44	2.80	2.47
3/16/2014	6105	B2-13	14	7.35	640	2.08	0.24	0.70	9.12	3.97	1.65
4/6/2014	6139	B2-13	14	6.54	660	0.31	0.16	0.10	109.79	1.62	1.15
6/25/2014	6242	B2-13	14	7.42	690	0.13	0.15		131.16	4.50	4.23
6/25/2014	6251	B2-13	14	7.55	740	0.19	0.15		127.03	3.49	3.16
4/6/2014	6150	B23R-4.5	3	7.3	270	1.04	0.16	0.87	84.27	2.31	1.11
6/26/2014	6254	B2-7	9	6.94	520	short	short	short	short	short	short
3/16/2014	6111	B3-1	1	7.76	610	0.14	0.15	0.37	18.68	0.16	0.00
4/6/2014	6141	B3-1	1	6.63	660	0.13	0.16	0.33	73.614	1.861	1.57
3/16/2014	6106	B3-14	14	7.52	830	0.22	0.24	0.12	7.95	0.18	0.00
4/6/2014	6158	B3-14	14	7.3	720	0.13	0.17	0.06	38.76	0.81	0.50
4/6/2014	6156	B3-3	3	7.63	700	0.25	0.17	0.67	55.58	2.16	1.74
6/25/2014	6240	B3-3	3	6.93	850	0.13	0.16	short	short	short	short

Date Collected	NAWA	Lysimeter	Downslope (m)	pH	Cond	NO_3-N	NH_4-N	PO4-P	DOC	TDN	DON
									mg L^{-1}		
6/25/2014	6248	B3-3	3	7.68	560	0.13	0.14	1.65	76.01	2.51	2.24
6/26/2014	6253	B3-3	3	6.57	500	0.02	0.17	1.6	70.95	2.28	2.09
6/25/2014	6249	B3-9	9	7.63	520	0.12	0.13	short	72.29	2.84	2.59
6/26/2014	6258	B3-9	9	7.31	610	short	short	short	67.06	2.11	short
3/16/2014	6112	C1-1	1	7.5	420	0.16	0.24	0.18	14.77	0.27	0.00
4/6/2014	6143	C1-1	1	7.1	380	0.14	0.17	0.55	short	short	short
6/2/2014	6214	C1-1	1	7.18	580	0.18	0.17	0.13	105.99	1.79	1.44
6/2/2014	6217	C1-1	14	8.25	760	0.15	0.13	1.14	143.76	2.27	1.99
3/16/2014	6107	C1-14	14	7.05	740	0.17	0.87	2.26	10.14	0.35	0.00
4/6/2014	6160	C1-14	14	7.88	640	0.14	0.16	2.25	56.57	1.13	0.83
5/28/2014	6223	C1-14	14	8.14	680	0.16	0.14	1.19	81.84	2.30	2.00
6/25/2014	6245	C1-14	14	7.41	820	0.15	15.22	short	30.52	25.95	10.58
3/16/2014	6110	C12R-1.5	1	7.97	440	0.15	0.23	0.18	11.61	0.21	0.00
4/6/2014	6146	C12R-1.5	1	7.11	490	0.13	0.17	0.06	81.39	3.62	3.31
4/6/2014	6140	C1-3	3	6.53	430	0.13	0.16	0.31	86.11	2.59	2.29
6/2/2014	6215	C1-3	3	6.78	580	0.18	0.24	0.19	137.82	3.21	2.78
4/6/2014	6142	C1-9	9	7.03	540	0.13	0.16	0.02	69.49	1.81	1.52
6/2/2014	6216	C1-9	9	7.45	820	0.18	0.17	0.11	138.51	3.14	2.79
4/6/2014	6153	C2-1	1	7.53	850	0.14	0.17	0.12	156.78	1.96	1.65
5/28/2014	6221	C2-13	14	7.59	580	0.16	0.20	0.78	58.32	1.58	1.22
6/25/2014	6241	C2-13	14	7.32	900	0.13	0.14	short	85.77	4.80	4.52
6/26/2014	6257	C2-13	14	7.26	610	short	short	short	70.55	2.57	short
6/2/2014	6211	C2-14	14	7.5	750	0.13	0.13	1.28	107.67	2.57	2.31

Date Collected	NAWA	Lysimeter	Downslope (m)	pH	Cond	NO_3-N	NH_4-N	PO4-P	DOC	TDN	DON
									mg L^{-1}		
4/6/2014	6157	C23R-1.5	1	7.63	790	0.14	0.18	0.02	112.98	2.55	2.22
4/6/2014	6134	C23R-4.5	3	6.44	380	0.14	0.17	0.09	31.96	0.42	0.11
6/2/2014	6220	C2-7	9	8.25	760	0.15	0.27	0.23	140.47	2.98	2.56
4/6/2014	6145	C3-1	1	7.26	960	0.15	0.16	0.14	178.54	2.23	1.92
3/16/2014	6108	C3-14	14		575	0.16	0.34	1.20	8.93	0.20	0.00
6/25/2014	6247	C3-14	14	7.61	750	0.13	0.14	short	53.22	2.04	1.78
3/16/2014	6109	C3-3	3	8.01	340	0.21	0.26	0.08	12.18	0.33	0.00
4/6/2014	6148	C3-3	3	7.22	360	0.16	0.17	0.07	54.73	1.22	0.89
6/25/2014	6244	C3-3	3	7.55	600	0.13	0.15	short	116.58	5.40	5.12
6/26/2014	6259	C3-3	3	7.29	480	0.09	0.18	0.14	64.70	2.15	1.88
6/2/2014	6212	C3-9	9	8.17	560	0.13	0.24	0.07	short	short	short
6/26/2014	6256	C3-9	9	7.27	700	short	short	short	short	short	short

APPENDIX VI

RAW DATA FOR THE SOIL COLLECTIONS OF WATER EXTRACTS FOR THE GRAVE STUDY

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06059	B1-1	2	1	0-15	6/23/2014	3.46	4.82	1.68	98.36	2.59
S06060	B1-1	2	1	15-30	6/23/2014	2.19	3.90	1.23	74.59	0.54
S06048	B1-14	2	14	0-15	6/23/2014	13.41	4.95	14.03	105.79	0.00
S06050	B12R-1.5	2	1.5	0-15	6/23/2014	4.58	4.41	5.42	125.56	4.27
S06641	B12R-1.5	2	1.5	15-30	6/23/2014	5.65	5.50	5.08	472.34	34.87
S06031	B1-3	2	3	0-15	6/23/2014	41.59	3.81	5.23	128.75	0.00
S06640	B1-3	2	3	15-30	6/23/2014	9.93	6.29	6.35	594.55	44.59
S06037	B1-9	2	9	0-8	6/23/2014	13.54	3.70	10.64	123.63	0.65
S06055	B2-1	2	1	0-15	6/23/2014	5.92	4.72	4.72	141.07	6.79
S06073	B2-13	2	13	0-15	6/23/2014	7.70	4.37	12.90	124.02	4.95
S06043	B23R-1.5	2	1.5	0-15	6/23/2014	5.09	5.42	6.46	129.12	5.22
S06054	B23R-4.5	2	4.5	0-10	6/23/2014	6.77	58.84	2.05	166.13	0.00
S06066	B2-7	2	7	0-5	6/23/2014	7.73	8.77	10.44	170.59	4.83
S06075	B3-1	2	1	15-30	6/23/2014	5.58	5.11	3.27	96.00	3.54
S06069	B3-14	2	14	0-8	6/23/2014	26.36	9.49	14.74	164.37	3.81
S06032	B3-3	2	3	0-15	6/23/2014	11.26	4.14	8.32	110.00	1.45
S06047	B3-3	2	3	15-30	6/23/2014	4.55	3.20	2.54	77.38	0.66
S06053	B3-9	2	9	0-7	6/23/2014	11.94	6.71	5.92	117.01	2.75
S06056	C1-1	1	1	0-15	6/23/2014	5.13	5.04	6.30	105.65	2.75
S06034	C1-1	1	1	15-30	6/23/2014	8.70	3.80	1.58	82.69	0.00

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06076	C12R-1.5	1	1.5	0-15	6/23/2014	8.59	8.41	4.02	206.14	5.70
S06052	C12R-1.5	1	1.5	15-30	6/23/2014	4.91	4.49	1.84	73..86	1.25
S06058	C12R-4.5	1	4.5	0-7	6/23/2014	5.71	5.34	2.87	123.18	5.13
S06065	C1-3	1	3	0-15	6/23/2014	5.76	4.13	1.45	107.45	5.25
S06066	C1-3	1	3	15-30	6/23/2014	4.99	4.94	5.89	362.40	25.90
S06309	C1-9	1	9	0-15	6/23/2014	5.78	4.26	3.09	251.47	15.84
S06062	C2-1	1	1	0-15	6/23/2014	3.72	2.72	5.39	228.20	28.53
S06028	C2-1	1	1	15-20	6/23/2014	7.98	3.55	3.22	99.35	0.00
S06079	C2-13	1	14	0-10	6/23/2014	4.27	3.75	2.71	143.49	5.93
S06033	C23R-1.5	1	1.5	0-15	6/23/2014	8.61	3.31	1.67	95.69	-0.02
S06071	C23R-1.5	1	1.5	15-30	6/23/2014	3.55	4.30	2.73	88.37	1.32
S06074	C23R-4.5	1	4.5	0-15	6/23/2014	4.24	4.19	8.19	76.48	0.00
S06068	C23R-4.5	1	4.5	15-30	6/23/2014	3.38	5.04	3.83	109.21	3.37
S06064	C2-7	1	7	0-15	6/23/2014	7.44	3.62	5.63	117.50	3.32
S06027	C3-1	1	1	0-15	6/23/2014	9.46	3.19	3.28	99.87	0.00
S06035	C3-1	1	1	15-30	6/23/2014	11.87	4.11	1.37	68.05	0.00
S06051	C3-14	1	14	0-15	6/23/2014	9.89	3.76	10.88	101.17	2.63
S06026	C3-3	1	3	0-15	6/23/2014	10.70	3.71	1.82	136.14	0.00
S06041	C3-3	1	3	15-30	6/23/2014	6.26	2.90	1.71	75.41	0.00
S06078	C3-9	1	9	0-15	6/23/2014	10.49	4.64	2.82	179.72	8.38
S06044	LB1-1	2	0	0-15	6/23/2014	4.73	3.01	4.58	117.71	4.94
S06046	LB1-1	2	0	15-30	6/23/2014	2.92	2.71	1.67	49.45	0.00
S06040	LB2-1	2	0	0-15	6/23/2014	12.66	3.30	6.25	104.31	0.00

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06042	LB2-1	2	0	15-30	6/23/2014	3.54	3.33	1.46	64.87	0.25
S06045	LB3-1	2	0	0-15	6/23/2014	6.63	3.85	7.48	110.55	5.69
S06070	LB4-1	2	0	0-15	6/23/2014	8.35	6.52	4.69	98.20	3.64
S06049	LB5-3	2	3	0-15	6/23/2014	8.31	4.98	3.95	103.19	3.95
S06072	LB6-9	2	9	0-15	6/23/2014	5.05	3.63	11.50	161.17	7.98
S06039	LC1-1	1	0	0-15	6/23/2014	9.74	3.66	11.28	113.62	0.00
S06029	LC1-1	1	0	15-30	6/23/2014	7.74	3.86	6.87	93.29	0.00
S06081	LC2-1	1	0	0-15	6/23/2014	4.67	3.56	6.89	141.38	2.40
S06080	LC2-1	1	0	15-30	6/23/2014	8.64	4.69	9.62	152.44	5.76
S06067	LC3-1	1	0	0-15	6/23/2014	5.07	4.30	4.09	96.12	2.01
S06036	LC3-1	1	0	15-30	6/23/2014	7.60	3.00	1.92	66.38	0.00
S06061	LC4-1	1	0	0-15	6/23/2014	4.25	3.64	3.04	106.50	4.20
S06038	LC4-1	1	0	15-30	6/23/2014	8.85	3.77	1.32	91.02	0.00
S06181	B1-1	2	1	0-15	7/23/2014	23.81	5.75	4.61	167.60	6.66
S06152	B1-1	2	1	15-30	7/23/2014	11.18	2.41	2.66	98.84	0.00
S06150	B1-14	2	14	0-15	7/23/2014	13.21	1.93	8.78	82.06	0.00
S06190	B12R-1.5	2	1.5	0-15	7/23/2014	16.73	5.02	5.43	117.32	0.00
S06306	B12R-1.5	2	1.5	15-30	7/23/2014	6.26	4.32	2.08	434.19	34.69
S06198	B12R-4.5	2	4.5	0-15	7/23/2014	6.19	3.02	3.02	104.76	5.10
S06196	B1-3	2	3	0-15	7/23/2014	9.03	8.82	5.12	135.67	0.00
S06311	B1-3	2	3	15-30	7/23/2014	8.96	5.59	6.16	589.87	43.57
S06197	B1-9	2	9	0-15	7/23/2014	7.48	3.53	3.53	86.05	2.64
S06156	B2-1	2	1	0-15	7/23/2014	8.57	2.41	4.35	105.92	1.46

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06193	B2-13	2	13	0-15	7/23/2014	19.49	6.77	14.11	135.97	2.40
S06329	B23R-1.5	2	1.5	0-15	7/23/2014	7.75	10.45	9.89	444.48	30.98
S06184	B23R-4.5	2	4.5	0-15	7/23/2014	12.78	5.15	9.76	159.86	6.12
S06187	B2-7	2	7	0-15	7/23/2014	14.65	5.95	5.21	147.98	7.24
S06177	B3-1	2	1	0-15	7/23/2014	12.64	6.12	11.45	178.03	8.83
S06170	B3-1	2	1	15-30	7/23/2014	9.20	2.35	4.84	74.31	0.00
S06191	B3-14	2	14	0-15	7/23/2014	14.11	17.80	5.32	120.30	0.00
S06637	B3-3	2	3	0-15	7/23/2014	10.33	1.67	4.38	398.80	33.02
S06638	B3-3	2	3	15-30	7/23/2014	6.80	5.50	4.02	282.31	22.33
S06188	B3-9	2	9	0-15	7/23/2014	17.18	6.16	15.15	196.52	11.29
S06178	C1-1	1	1	0-15	7/23/2014	12.82	3.49	5.41	102.29	0.69
S06179	C1-1	1	1	15-30	7/23/2014	7.02	2.50	1.64	76.87	0.00
S06172	C1-14	1	14	0-15	7/23/2014	14.46	2.70	13.61	98.27	1.70
S06168	C12R-1.5	1	1.5	0-15	7/23/2014	17.75	5.16	4.65	110.65	2.25
S06165	C12R-1.5	1	1.5	15-30	7/23/2014	9.54	2.73	2.12	102.70	0.00
S06162	C12R-4.5	1	4.5	0-15	7/23/2014	14.89	2.88	3.52	166.43	4.58
S06161	C1-3	1	3	0-15	7/23/2014	11.33	2.69	4.60	114.17	1.15
S06310	C1-3	1	3	15-30	7/23/2014	6.96	2.07	2.05	279.99	23.35
S06153	C1-9	1	9	0-15	7/23/2014	18.55	2.87	4.67	122.15	1.20
S06167	C2-1	1	1	0-15	7/23/2014	14.65	3.82	6.50	110.98	0.00
S06175	C2-1	1	1	15-30	7/23/2014	6.60	2.19	1.49	96.25	8.20
S06183	C2-13	1	13	0-15	7/23/2014	9.83	6.72	12.80	152.45	6.81
S06154	C23R-1.5	1	1.5	0-15	7/23/2014	14.49	3.87	4.29	126.04	2.80

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06308	C23R-1.5	1	1.5	15-30	7/23/2014	8.92	6.71	4.05	507.21	32.25
S06176	C23R-4.5	1	4.5	0-15	7/23/2014	5.14	4.52	7.10	85.06	0.00
S06160	C23R-4.5	1	4.5	15-30	7/23/2014	6.62	3.21	4.30	108.47	0.45
S06182	C2-7	1	7	0-15	7/23/2014	14.14	9.36	6.10	179.42	1.19
S06325	C3-1	1	1	0-15	7/23/2014	8.16	2.97	7.07	272.90	20.99
S06326	C3-1	1	1	15-30	7/23/2014	7.40	3.45	6.12	510.60	42.04
S06185	C3-14	1	14	0-15	7/23/2014	12.16	3.65	13.98	106.47	1.05
S06163	C3-3	1	3	0-15	7/23/2014	12.28	4.55	6.76	118.75	2.25
S06174	C3-3	1	3	15-30	7/23/2014	4.12	28.25	1.67	63.55	0.00
S06192	C3-9	1	9	0-15	7/23/2014	14.17	4.93	7.75	201.84	7.50
S06159	LB1-1	2	0	0-15	7/23/2014	13.24	2.74	4.63	112.84	0.04
S06158	LB1-1	2	0	15-30	7/23/2014	5.66	2.27	1.87	139.30	9.50
S06151	LB2-1	2	0	0-15	7/23/2014	23.19	2.71	7.16	116.84	2.48
S06195	LB2-1	2	0	15-30	7/23/2014	4.58	3.38	3.38	86.78	2.15
S06307	LB3-1	2	0	15-30	7/23/2014	6.77	4.51	3.55	512.73	38.13
S06169	LB3-1	2	0	0-15	7/23/2014	17.22	2.62	6.43	109.41	0.00
S06171	LB4-1	2	0	0-15	7/23/2014	9.53	5.07	8.51	118.25	3.95
S06180	LB5-3	2	3	0-15	7/23/2014	16.91	3.33	9.78	140.43	4.34
S06157	LC1-1	1	0	0-15	7/23/2014	10.82	2.64	8.19	94.03	0.00
S06189	LC1-1	1	0	15-30	7/23/2014	4.18	3.99	5.73	145.17	4.63
S06324	LC2-1	1	0	0-15	7/23/2014	6.50	2.60	7.79	247.80	20.05
S06173	LC2-1	1	0	15-30	7/23/2014	2.74	13.26	1.51	76.20	0.00
S06166	LC3-1	1	0	0-15	7/23/2014	11.75	2.90	3.97	134.74	2.95

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06149	LC3-1	1	0	15-30	7/23/2014	5.81	1.95	2.27	73.23	0.00
S06194	LC4-1	1	0	0-15	7/23/2014	10.03	5.43	4.87	180.07	13.51
S06155	LC4-1	1	0	15-30	7/23/2014	7.87	2.57	1.40	76.21	0.00
S06186	B23R-4.5	2	4.5	15-30	7/23/2014	3.57	3.18	1.79	68.19	0.00
S06583	B1-1	2	1	0-15	9/29/2014	3.97	3.98	2.99	252.26	24.10
S06554	B1-1	2	1	15-30	9/29/2014	4.47	4.48	3.28	207.58	16.20
S06592	B1-14	2	14	0-15	9/29/2014	5.67	5.69	15.10	252.57	25.65
S06559	B12R-1.5	2	1.5	0-15	9/29/2014	12.02	3.37	8.52	322.69	24.61
S06580	B12R-1.5	2	1.5	15-30	9/29/2014	7.17	6.17	4.05	304.50	30.01
S06582	B12R-4.5	2	4.5	0-15	9/29/2014	9.14	2.92	5.50	331.07	25.04
S06553	B1-3	2	3	0-15	9/29/2014	6.11	6.13	7.71	306.71	29.21
S06560	B1-3	2	3	15-30	9/29/2014	5.15	5.16	2.71	356.51	285.26
S06584	B1-9	2	9	0-15	9/29/2014	6.44	6.46	7.06	350.46	30.15
S06563	B2-1	2	1	0-15	9/29/2014	5.63	5.64	7.25	277.17	163.04
S06544	B2-13	2	13	0-15	9/29/2014	4.29	4.30	17.25	283.02	29.99
S06565	B23R-1.5	1	1.5	0-15	9/29/2014	16.10	4.71	11.11	397.08	32.93
S06548	B23R-4.5	2	4.5	0-15	9/29/2014	11.82	3.63	3.79	422.84	34.97
S06585	B2-7	2	7	0-17	9/29/2014	6.09	6.11	3.99	325.73	27.81
S06581	B3-1	2	1	0-15	9/29/2014	5.39	5.41	9.85	333.58	29.16
S06552	B3-1	2	1	15-30	9/29/2014	4.32	2.14	4.91	165.36	12.33
S06546	B3-14	2	14	0-15	9/29/2014	26.67	8.79	11.00	430.46	16.17
S06591	B3-3	2	3	0-15	9/29/2014	4.07	4.08	8.80	344.73	35.71
S06561	B3-3	2	3	15-30	9/29/2014	4.19	4.20	1.13	254.58	22.18

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06577	B3-9	2	9	0-15	9/29/2014	31.25	10.42	5.75	447.28	12.54
S06562	C1-1	1	1	0-15	9/29/2014	4.83	4.84	9.17	342.75	9.14
S06573	C1-1	1	1	15-30	9/29/2014	3.73	3.74	2.27	183.77	13.83
S06555	C1-14	1	14	0-15	9/29/2014	7.85	7.87	20.40	392.96	327.46
S06539	C12R-1.5	1	1.5	0-15	9/29/2014	9.27	2.33	3.77	214.89	16.76
S06575	C12R-1.5	1	1.5	15-30	9/29/2014	5.46	2.60	2.25	213.18	15.46
S06547	C12R-4.5	1	4.5	0-15	9/29/2014	13.37	2.81	4.12	345.00	26.30
S06590	C1-3	1	3	0-15	9/29/2014	5.09	5.10	3.90	297.04	25.19
S06595	C1-3	1	3	15-30	9/29/2014	3.76	3.77	1.19	187.90	11.69
S06540	C1-9	1	9	0-15	9/29/2014	4.91	4.92	5.05	325.42	28.72
S06556	C2-1	1	1	0-15	9/29/2014	4.00	4.01	4.91	256.01	79.18
S06574	C2-1	1	1	15-30	9/29/2014	6.91	6.08	3.95	711.92	54.46
S06570	C2-13	1	13	0-15	9/29/2014	34.12	9.90	27.84	432.61	32.02
S06558	C23R-1.5	1	1.5	0-15	9/29/2014	9.20	2.51	5.41	228.88	17.15
S06543	C23R-1.5	1	1.5	15-30	9/29/2014	4.08	1.70	1.61	148.22	9.73
S06589	C23R-4.5	1	4.5	0-15	9/29/2014	8.47	1.53	1.83	273.91	19.59
S06588	C23R-4.5	1	4.5	15-30	9/29/2014	7.68	1.39	1.51	185.46	15.51
S06571	C2-7	1	7	0-15	9/29/2014	9.24	2.68	4.92	206.86	17.89
S06545	C3-1	1	1	0-15	9/29/2014	8.14	2.65	4.70	235.72	17.62
S06567	C3-1	1	1	15-30	9/29/2014	5.56	3.35	2.06	355.02	24.11
S06551	C3-14	1	14	0-15	9/29/2014	17.94	4.52	22.11	376.00	29.55
S06537	C3-3	1	3	0-15	9/29/2014	10.63	1.72	3.13	232.83	18.43
S06569	C3-3	1	3	15-30	9/29/2014	2.94	1.74	1.37	112.05	8.52

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06564	C3-9	1	9	0-15	9/29/2014	11.25	5.11	6.58	401.32	32.19
S06572	LB1-1	2	3	0-15	9-29-2014	4.03	4.04	1.14	174.27	12.14
S06538	LB1-1	2	3	15-30	9/29/2014	5.04	5.06	3.70	275.66	24.14
S06549	LB2-1	2	0	0-15	9/29/2014	7.39	7.41	7.95	292.23	21.19
S06579	LB2-1	2	0	15-30	9/29/2014	4.32	4.33	6.24	551.05	46.22
S06597	LB3-1	2	0	0-15	9/29/2014	5.44	5.45	8.30	355.66	33.54
S06598	LB3-1	2	0	15-30	9/29/2014	6.62	6.64	4.23	507.62	37.03
S06542	LB4-1	2	0	0-15	9/29/2014	5.50	5.51	13.89	294.32	26.89
S06599	LB5-3	2	0	0-15	9/29/2014	5.64	5.65	8.00	259.47	24.19
S06600	LB6-9	2	9	0-15	9/29/2014	8.09	8.11	18.54	436.33	36.52
S06568	LC1-1	1	0	0-15	9/29/2014	6.34	6.36	12.11	267.68	21.31
S06566	LC1-1	1	0	15-30	9/29/2014	7.17	7.19	14.43	225.25	87.74
S06587	LC2-1	1	0	0-15	9/29/2014	11.15	3.53	7.10	208.02	16.93
S06594	LC2-1	1	0	15-30	9/29/2014	6.04	1.24	2.24	187.49	12.75
S06578	LC3-1	1	0	0-15	9/29/2014	3.91	3.92	5.38	234.84	18.92
S06550	LC3-1	1	0	15-30	9/29/2014	4.41	4.42	1.84	174.38	11.48
S06541	LC4-1	1	0	0-15	9/29/2014	4.07	4.08	4.71	221.09	21.03
S06576	LC4-1	1	0	15-30	9/29/2014	4.75	4.76	2.31	327.93	21.53
S06586	B23R-4.5	2	4.5	15-30	9/29/2014	7.91	2.43	6.48	228.54	16.80
S06749	B1-1	2	1	0-15	12/13/2014	10.87	3.90	1.68	231.34	16.93
S06750	B1-1	2	1	15-30	12/13/2014	4.99	3.49	0.07	222.41	15.04
S06754	B1-14	2	14	0-15	12/13/2014	9.92	2.82	11.13	169.49	11.08
S06765	B12R-1.5	2	1.5	0-15	12/13/2014	13.42	3.53	2.85	164.69	11.21

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06766	B12R-1.5	2	1.5	15-30	12/13/2014	8.81	2.59	2.59	333.11	25.95
S06767	B12R-1.5	2	4.5	0-15	12/13/2014	8.36	5.12	4.04	229.24	18.62
S06751	B1-3	2	3	0-15	12/13/2014	9.19	4.23	3.45	243.92	18.12
S06752	B1-3	2	3	15-30	12/13/2014	6.80	6.17	2.67	444.75	34.79
S06753	B1-9	2	9	0-15	12/13/2014	15.15	3.44	7.17	174.34	12.70
S06755	B2-1	2	1	0-15	12/13/2014	47.75	2.83	3.97	286.78	0.54
S06758	B2-13	2	13	0-15	12/13/2014	14.40	5.09	14.19	246.69	18.56
S06768	B23R-1.5	2	1.5	0-15	12/13/2014	12.73	3.52	5.11	261.46	20.40
S06770	B23R-4.5	2	4.5	0-15	12/13/2014	17.12	2.59	4.60	241.46	19.02
S06757	B2-7	2	7	0-15	12/13/2014	10.12	3.93	1.07	204.50	14.08
S06759	B3-1	2	1	0-15	12/13/2014	12.64	4.50	7.32	290.08	23.86
S06760	B3-1	2	1	15-30	12/13/2014	7.32	3.96	1.17	251.85	17.32
S06764	B3-14	2	14	0-15	12/13/2014	11.37	2.89	5.49	169.46	8.91
S06761	B3-3	2	3	0-15	12/13/2014	13.42	6.47	5.09	303.49	26.13
S06762	B3-3	2	3	15-30	12/13/2014	6.91	5.12	2.04	279.49	24.48
S06763	B3-9	2	9	0-15	12/13/2014	16.41	4.40	2.07	143.79	6.66
S06726	C1-1	1	1	0-15	12/13/2014	24.29	11.28	5.68	268.12	20.44
S06727	C1-1	1	1	15-30	12/13/2014	4.32	10.89	2.76	178.00	14.07
S06731	C1-14	1	14	0-15	12/13/2014	11.57	4.95	13.20	159.26	10.38
S06742	C12R-1.5	1	1.5	0-15	12/13/2014	15.22	6.66	4.28	274.23	17.93
S06743	C12R-1.5	1	1.5	15-30	12/13/2014	6.18	4.09	0.94	342.91	26.09
S06744	C12R-4.5	1	4.5	0-15	12/13/2014	8.82	3.52	1.47	264.19	20.16
S06728	C1-3	1	3	0-15	12/13/2014	11.99	3.18	2.25	208.26	14.88

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06729	C1-3	1	3	15-30	12/13/2014	5.01	3.52	2.93	192.53	13.58
S06730	C1-9	1	9	0-15	12/13/2014	18.57	7.14	3.28	330.58	32.44
S06732	C2-1	1	1	0-15	12/13/2014	9.26	5.68	3.28	176.03	13.14
S06733	C2-1	1	1	15-30	12/13/2014	6.94	6.91	2.54	465.53	37.16
S06735	C2-13	1	13	0-15	12/13/2014	12.54	5.06	14.32	192.22	12.03
S06745	C23R-1.6	1	1.5	0-15	12/13/2014	8.78	6.06	7.05	256.51	18.76
S06746	C23R-1.5	1	1.5	15-30	12/13/2014	5.49	3.42	0.97	172.58	11.92
S06747	C23R-4.5	1	4.5	0-15	12/13/2014	8.04	5.08	5.55	293.07	20.55
S06748	C23R-4.5	1	4.5	15-30	12/13/2014	4.20	3.15	0.25	155.85	12.72
S06734	C2-7	1	7	0-15	12/13/2014	13.02	14.35	6.19	216.62	16.67
S06736	C3-1	1	1	0-15	12/13/2014	9.06	3.22	2.79	201.33	14.70
S06737	C3-1	1	1	15-30	12/13/2014	29.72	4.04	3.32	402.08	30.40
S06741	C3-14	1	14	0-15	12/13/2014	13.66	3.98	11.52	496.43	34.15
S06738	C3-3	1	3	0-15	12/13/2014	12.93	4.33	3.10	219.44	15.66
S06739	C3-3	1	3	15-30	12/13/2014	5.11	3.08	0.79	181.94	12.75
S06740	C3-9	1	9	0-15	12/13/2014	17.70	5.02	2.44	178.38	10.39
S06716	LB1-1	2	0	0-15	12/13/2014	9.90	3.11	1.54	156.65	8.90
S06717	LB1-1	2	0	15-30	12/13/2014	10.12	2.91	0.55	176.45	12.24
S06718	LB2-1	2	0	0-15	12/13/2014	12.74	5.92	3.92	138.74	11.04
S06719	LB2-1	2	0	15-30	12/13/2014	5.02	4.55	1.35	60.27	0.00
S06720	LB3-1	2	0	0-15	12/13/2014	10.91	1.85	8.01	267.99	21.11
S06721	LB3-1	2	0	15-30	12/13/2014	21.79	0.91	8.22	192.10	14.71
S06722	LB4-1	2	0	0-15	12/13/2014	6.11	4.95	8.07	222.75	17.81

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06723	LB4-1	2	0	15-30	12/13/2014	8.66	4.26	8.59	226.57	13.15
S06724	LB5-3	2	0	0-15	12/13/2014	7.59	11.44	7.61	223.84	18.66
S06725	LB6-9	2	0	0-15	12/13/2014	8.19	3.79	9.94	220.61	17.93
S06708	LC1-1	1	0	0-15	12/13/2014	12.35	4.54	6.56	228.65	14.65
S06709	LC1-1	1	0	15-30	12/13/2014	5.23	3.15	3.25	246.79	17.68
S06710	LC2-1	1	0	0-15	12/13/2014	15.85	0.00	1.31	75.34	0.00
S06711	LC2-1	1	0	15-30	12/13/2014	18.07	2.22	1.15	92.37	3.06
S06712	LC3-1	1	0	0-15	12/13/2014	6.87	2.24	2.00	157.91	9.77
S06713	LC3-1	1	0	15-30	12/13/2014	5.26	2.49	0.10	85.01	2.84
S06714	LC4-1	1	0	0-15	12/13/2014	8.55	1.00	5.58	201.62	15.34
S06715	LC4-1	1	0	15-30	12/13/2014	6.86	4.87	1.94	508.76	38.45
S06756	B2-1	2	1	15-30	12/13/2014	4.30	3.87	2.33	368.37	31.27
S06769	B23R-1.5	2	1.5	15-30	12/13/2014	6.75	4.73	2.38	405.81	36.05
S06771	B23R-4.5	2	4.5	15-30	12/13/2014	5.88	2.25	0.00	217.17	17.83
S06790	C1-1	1	1	0-15	2/10/2015	16.26	3.88	6.30	243.00	15.37
S06791	C1-1	1	1	15-30	2/10/2015	6.35	1.60	2.01	152.00	9.88
S06795	C1-14	1	14	0-15	2/10/2015	8.93	5.65	13.13	201.32	8.40
S06806	C12R-1.5	1	1.5	0-15	2/10/2015	10.97	5.01	5.02	13.02	0.00
S06807	C12R-1.5	1	1.5	15-30	2/10/2015	4.01	2.85	1.18	216.49	16.18
S06808	C12R-4.5	1	4.5	0-15	2/10/2015	12.54	5.48	2.82	187.14	9.37
S06792	C1-3	1	3	0-15	2/10/2015	5.78	1.86	3.20	286.37	18.68
S06794	C1-9	1	9	0-15	2/10/2015	12.16	2.85	1.83	153.90	8.56
S06796	C2-1	1	1	0-15	2/10/2015	6.98	2.53	5.43	208.72	17.84

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P	DOC	DON
								μg g soil $^{-1}$		
S06797	C2-1	1	1	15-30	2/10/2015	6.09	1.89	1.76	318.98	25.32
S06799	C2-13	1	13	0-15	2/10/2015	13.07	4.37	15.02	238.46	15.05
S06809	C23R-1.5	1	1.5	0-15	2/10/2015	8.84	4.83	5.32	229.58	16.71
S06810	C23R-1.5	1	1.5	15-30	2/10/2015	4.17	4.96	4.01	261.99	12.99
S06811	C23R-4.5	1	4.5	0-15	2/10/2015	6.26	3.31	5.75	209.97	14.97
S06798	C2-7	1	7	0-15	2/10/2015	10.31	4.73	3.84	150.94	6.01
S06800	C3-1	1	1	0-15	2/10/2015	8.12	2.90	2.88	429.98	29.55
S06801	C3-1	1	1	15-30	2/10/2015	10.22	1.74	3.77	244.66	16.03
S06805	C3-14	1	14	0-15	2/10/2015	15.40	5.69	13.33	219.60	7.33
S06802	C3-3	1	3	0-15	2/10/2015	8.08	4.37	2.82	186.70	17.00
S06803	C3-3	1	3	15-30	2/10/2015	3.78	0.95	1.08	153.30	9.77
S06804	C3-9	1	9	0-15	2/10/2015	11.03	1.47	5.53	259.07	19.23
S06772	LC1-1	1	0	0-15	2/10/2015	7.91	3.43	6.93	197.19	12.84
S06773	LC1-1	1	0	15-30	2/10/2015	5.46	2.61	1.38	156.11	10.14
S06774	LC2-1	1	0	0-15	2/10/2015	9.91	2.48	2.60	124.32	4.63
S06775	LC2-1	1	0	15-30	2/10/2015	5.27	3.14	0.54	162.45	8.00
S06776	LC3-1	1	0	0-15	2/10/2015	7.03	2.10	1.30	86.61	0.78
S06777	LC3-1	1	0	15-30	2/10/2015	6.82	3.54	0.71	134.59	6.54
S06778	LC4-1	1	0	0-15	2/10/2015	7.79	5.35	1.49	195.45	10.51
S06779	LC4-1	1	0	15-30	2/10/2015	5.57	2.40	0.40	131.67	6.46
S06813	B1-1	2	1	0-15	2/10/2015	8.68	4.07	2.33	196.74	15.06
S06814	B1-1	2	1	15-30	2/10/2015	5.27	4.97	6.41	182.18	20.66
S06818	B1-14	2	14	0-15	2/10/2015	16.24	3.58	10.80	205.52	10.90

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P μg g soil $^{-1}$	DOC	DON
S06829	B12R-1.5	2	1.5	0-15	2/10/2015	9.39	3.30	5.25	285.86	24.06
S06830	B12R-1.5	2	1.5	15-30	2/10/2015	6.69	6.19	2.24	250.09	12.06
S06831	B12R-4.5	2	4.5	0-15	2/10/2015	8.55	5.94	5.02	172.38	15.33
S06815	B1-3	2	3	0-15	2/10/2015	8.69	1.83	5.39	235.70	18.16
S06817	B1-9	2	9	0-15	2/10/2015	10.79	2.55	2.71	179.38	7.21
S06819	B2-1	2	1	0-15	2/10/2015	10.82	2.76	7.14	320.85	25.61
S06822	B2-13	2	13	0-15	2/10/2015	13.27	2.69	5.22	176.77	8.90
S06832	B23R-1.5	2	1.5	0-15	2/10/2015	13.12	5.53	4.21	173.70	1.23
S06834	B23R-4.5	2	4.5	0-15	2/10/2015	11.40	5.67	3.10	223.59	12.11
S06821	B2-7	2	7	0-15	2/10/2015	11.08	2.98	4.71	318.11	25.07
S06823	B3-1	2	1	0-15	2/10/2015	8.59	3.72	6.36	283.52	18.27
S06824	B3-1	2	1	15-30	2/10/2015	5.33	2.56	2.31	256.48	26.89
S06828	B3-14	2	14	0-15	2/10/2015	11.88	4.39	7.16	202.61	13.66
S06825	B3-3	2	3	0-15	2/10/2015	10.37	2.92	6.51	206.85	11.83
S06826	B3-3	2	3	15-30	2/10/2015	7.59	2.03	2.87	364.89	23.73
S06827	B3-9	2	9	0-15	2/10/2015	22.59	4.74	4.57	206.23	13.19
S06780	LB1-1	2	0	0-15	2/10/2015	7.53	4.48	3.06	321.75	28.57
S06781	LB1-1	2	0	15-30	2/10/2015	5.76	4.91	1.72	353.60	25.79
S06782	LB2-1	2	0	0-15	2/10/2015	8.64	3.81	4.36	165.73	11.04
S06783	LB2-1	2	0	15-30	2/10/2015	3.21	2.85	0.74	122.37	6.17
S06784	LB3-1	2	0	0-15	2/10/2015	10.03	6.32	5.24	304.27	21.43
S06785	LB3-1	2	0	15-30	2/10/2015	10.06	7.33	6.40	225.18	7.11
S06786	LB4-1	2	0	0-15	2/10/2015	12.33	2.46	4.83	177.07	11.78

NaWA	Sample Name	Type	Distance m	Depth cm	Collection Date	NO_3-N	NH_4-N	PO_4-P μg g soil $^{-1}$	DOC	DON
S06787	LB4-1	2	0	15-30	2/10/2015	10.28	4.64	6.02	318.44	36.94
S06788	LB5-3	2	0	15-30	2/10/2015	8.53	3.87	2.56	231.10	16.68
S06789	LB6-9	2	0	0-15	2/10/2015	8.24	3.10	10.75	242.41	17.07
S06820	B2-1	2	1	15-30	2/10/2015	7.70	2.71	8.03	444.05	34.61
S06833	B23R-1.5	2	1.5	15-30	2/10/2015	11.14	9.08	4.72	630.13	41.52